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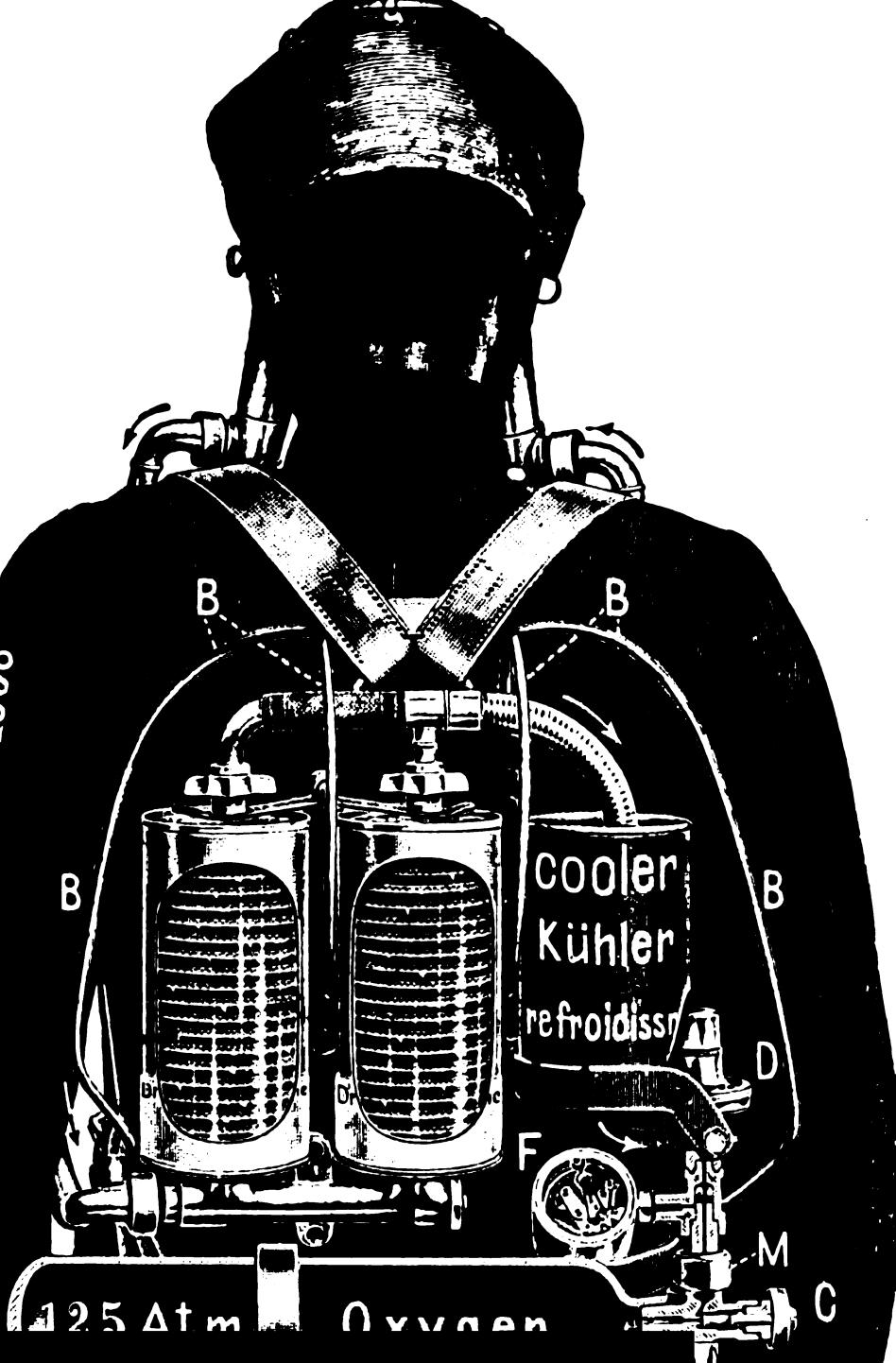
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# *Mining and Metallurgy*

American Institute of Mining, Metallurgical, and Petroleum Engineers



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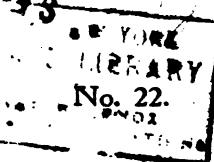
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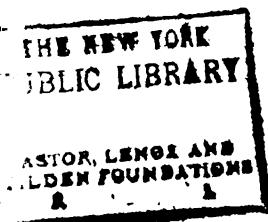




JULY.

1908.

# Bi-Monthly Bulletin OF THE American Institute of Mining Engineers

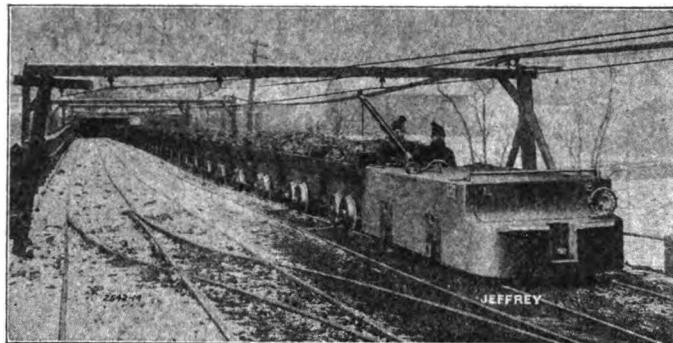


PUBLISHED BY THE AMERICAN INSTITUTE OF MINING ENGINEERS

Editorial Office at 29 West 39th Street,  
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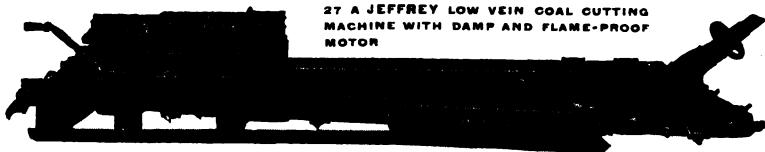
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Mining and Metallurgy

BI-MONTHLY BULLETIN  
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No. 22

JULY

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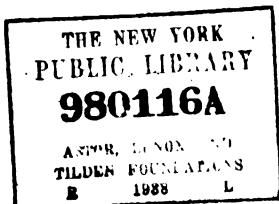
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**BI-MONTHLY BULLETIN.****SECTION I.—INSTITUTE ANNOUNCEMENTS.**

This section contains announcements of general interest to the members of the Institute, but not always of sufficient permanent value to warrant republication in the volumes of the *Transactions*.

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**SECTION II.—TECHNICAL PAPERS AND DISCUSSIONS.**

[The American Institute of Mining Engineers does not assume responsibility for any statement of fact or opinion advanced in its papers or discussions.]

A detailed list of the papers contained in this section is given in the Table of Contents. They have been so printed and arranged (blank pages being left when necessary) that they can be separately removed for classified filing, or other independent use.

A small stock of separate pamphlets, duplicating the technical papers given in Section II. of this Bulletin, is reserved for those who desire extra copies of any single paper.

Comments or criticisms upon all papers given in this section, whether private corrections of typographical or other errors or communications for publication as "Discussions," or independent papers on the same or a related subject, are earnestly invited.

All communications concerning the contents of this Bulletin should be addressed to Dr. Joseph Struthers, Assistant Secretary and Editor, 29 W. 39th St., New York City (Telephone number 4600 Bryant).

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\* SECRETARY'S NOTE.—The Council is the professional body, having charge of the election of members, the holding of meetings (except business meetings), and the publication of papers, proceedings, etc. The Board of Directors is the body legally responsible for the business management of the Corporation, and is therefore, for convenience, composed of members residing in New York.

## ANNOUNCEMENTS.

### Award of a Gold Medal to the Institute.

The Jury of Awards of the Jamestown Ter-Centennial Exposition has conferred a gold medal, the highest distinction within its power, on the American Institute of Mining Engineers for the excellence of its publications during the past decade.

A half-tone photographic reproduction of both sides of the medal is given in the accompanying illustration.



### Office Facilities for Visiting Members.

A separate room in the suite occupied by the American Institute of Mining Engineers on the ninth floor of the United Engineering Society Building, has been equipped with furniture and telephone extension for the temporary use of members of the Institute or of sister societies, or visitors suitably accredited.

Members of the Institute visiting New York for a short time, who need office facilities during their stay, or members residing in the city who need temporary office accommodation, can

arrange to have set apart for their exclusive use a room, equipped with office furniture, telephone, etc., in the suite of the Institute. It is not the intention to give possession of the room to any individual for an indefinite time, but to offer to members of the Institute an opportunity to acquire a well-located, well-equipped business headquarters to carry on transactions which would not warrant the establishment of a permanent office. The room devoted to this purpose is entirely separate from the reception- and writing-rooms for the general use of the members. A small fee will be required for the use of the facilities furnished. For the conditions of this privilege, inquiry should be made at the office of the Secretary of the Institute.

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### **The Birmingham Meeting of the Institute.**

The 95th Meeting of the Institute for the reading and discussion of papers will be held, as announced by Special Circular No. 1, at Birmingham, Ala., beginning Tuesday evening, Sept. 29, 1908. Further particulars of the sessions, entertainments, and excursions in Birmingham and vicinity will be given in a later circular from this office, or in the programme of the Local Committee. At present, it must suffice to say that the first session, on Tuesday evening, will be one of special interest, which members are earnestly advised to attend; that, for the succeeding sessions, many papers of professional importance to mining engineers, economic geologists, and metallurgists have been already secured; and that the excursions and entertainments projected by the Local Committee promise to be in the highest degree profitable and enjoyable.

Arrangements are being made for a special-train excursion after the meeting, to spend three days at Chattanooga and two days at Ducktown. In both places the party will receive generous hospitality, expressed not only in social entertainment but also in local excursions, visits to mines and works, technical sessions, etc., the particulars of which will be announced hereafter. The trip is so arranged that Sunday may be spent at Chattanooga, upon Lookout Mountain, and, if desired, in visits to the battlefields and the National Cemetery.

Further information has already been given in Special Circular No. 1, which will be sent to members and others, on application to the Secretary's office.

All members who have not yet advised the Secretary as to attendance at the Birmingham meeting are earnestly requested to do so at once, in order that arrangements now pending may be completed.

---

### Meetings of Other Societies.

*The American Society of Mechanical Engineers* held its Spring Meeting at Detroit, June 23 to 26, 1908, with an attendance exceeding 700 members and guests. One session was devoted to a symposium upon machinery for hoisting and conveying materials. Four papers were presented upon different types of this class of machinery, with data upon their design and performance, and the subject drew out much discussion. The Gas Power Section of the Society held a largely attended session, at which, in addition to the regular papers, material was presented with a view to the standardization of the elements entering into the generation and use of gas for power and other purposes.

At other sessions there were papers upon specific heat of super heated steam, engine-performance, and steam-condensers. Hydraulics received attention in papers upon the use of Pitot tubes and the application of surge-tanks to water-power plants.

The visiting members were invited to witness the launching of a 12,500-ton freight-steamer, the *Daniel B. Meacham*, by the Great Lakes Engineering Works near Detroit; and an evening lecture upon stellar photography, by Prof. John A. Brashear, astronomer and scientist, of Allegheny, Pa., contributed to the enjoyment of the meetings.

*The American Institute of Electrical Engineers* held its twenty-fifth Annual Convention at Atlantic City, N. J., June 29 to July 2, 1908. The technical papers were of a high order of merit; several of them, notably the paper by Dr. Charles P. Steinmetz on The General Equations of the Electric Circuit, and that by Prof. E. E. F. Creighton on Lightning Phenomena

and Lightning Protective Apparatus, were classical in their nature and treatment. Including the address of President Henry G. Stott on The Evolution of Engineering, there were presented for discussion 35 papers, covering approximately 775 pages of the Institute *Proceedings*. There were eight separate sessions, occupying a total of 26 hours, devoted to technical papers and discussions. The papers were presented in abstract only, in order to give time for the discussions, in which at least 125 members participated. These discussions as printed will cover approximately 250 pages of the *Proceedings*.

There were registered 475 members and guests, including 12 out of a total of 18 past-Presidents of the Institute. At one of the sessions President Stott commented on this by saying: "As a nation we frequently ask, 'What shall we do with our ex-Presidents?' As a society of engineers we solve this problem by saying, 'We make our ex-Presidents continue to work for the Institute.'"

Past-President Samuel Sheldon, in behalf of the President and Board of Directors of the Institute, presented past-President Charles F. Scott with a set of engrossed resolutions as a token of appreciation of Mr. Scott's earnest, faithful, and efficient service in connection with the construction of the United Engineering Society Building. Mr. Scott acknowledged this added honor with characteristic gentleness and modesty.

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### Unveiling of the Thurston Memorial.

The Thurston Memorial was unveiled at Sibley College, Cornell University, on June 16, 1908. This memorial, presented by the Alumni of Sibley College, consists of a bronze tablet, the work of the celebrated American sculptor, Mr. Hermann A. McNeil, who was at one time an instructor under Dean Thurston in the Department of Drawing in Sibley College. At some future time the memorial will be permanently mounted on the first floor of Sibley Dome on the wall to the right of the main entrance. Professor Carpenter presided over the ceremonies, and addresses were delivered by ex-President Andrew D. White, Director Albert F. Smith, John H. Barr, and Henry P. Du Bois. The exercises occupied about an hour.

## Special Inquiry.

*Do you Possess, or Can you Obtain, and Will you Give, or Sell, to the Institute Library*

Early Volumes of the following Proceedings and Journals?

**American Chemical Society. Journal.**

Wanting: Vol. 3, Nos. 8-12 (1881); Vol. 4 (1882); Vol. 5 (1883); Vol. 6, Nos. 1-3 (1884).

**American Foundrymen's Association. Journal.**

Wanting: Vols. 1-4; Vol. 5, Nos. 26, 28-30; Vol. 6, Nos. 31-35; Vol. 7, No. 41; Vol. 8, No. 48.

**Australian Mining Standard, Sydney (Australia).**

Wanting: Vols. 1-10 (1888-'94); Vol. 11 (1895), No. 370, and all Nos. before No. 356 and all after No. 372; Vol. 13, Nos. 429, 440, 441, 448, 460, 462, 468, 472, 476; Vol. 13, 479, 490, 492, 497; Vol. 14, Nos. 512, 515, 518; Vol. 15, Nos. 536, 545, 550, 552-554, 557, 559, 562, 566, 567, 581; Vol. 17, Jan.-June; Vol. 18, p. 1-425 (July-Oct. 11); Vol. 19, Nos. 637-639, 647; Vol. 20, Nos. 661, 662, 680, and p. 543 and index; Vols. 21-27.

**Chemical Society of London. Journal.**

Wanting: Vols. 1-26.

**Deutsche Chemische Gesellschaft. Berichte.**

Wanting: Vols. 1-6 (1868-'74).

**Foundry.**

Wanting: Vols. 1-22 (1892-1902), and Vol. 23 to No. 133 (1903).

**Mining and Scientific Press.**

Wanting: Vols. 1-19 (1860-'69); 24-33, 1872-'76.

**Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde.**

Wanting: 1830-'38.

**New Zealand Mines Record, Wellington, N. Z.**

Wanting: Vols. 1-6 (1896-1902).

**Queensland Government Mining Journal.**

Wanting: Vols. 1-4.

**Revue Universelle des Mines, etc., Liége.**

Wanting: Series 1; Vols. 1-4 of Series 2 (1857-'78); Vols. 2, 9, 11, 15, and 18 of Series 3. Table des Matières de la première et de la seconde série (1857-'76, 1877-'87).

**Société de l'Industrie Minérale. Bulletin.**

Wanting: Series 1, Vols. 1-15; Series 2, Vols. 1-7.

*Atlas.*

Wanting: Pts. 2 of Vols. 11, 13, 14; also Pts. 28-33 of Vol. 2.

*Compte Rendu.*

Wanting: Jan. to March, 1879, and July, 1900.

**Zeitschrift für Angewandte Chemie.**

Wanting: Vols. 1-11 (1887-'99); Vols. 14, 16-17 (1901, 1903-'04).

**Zeitschrift für Anorganische Chemie.**

Wanting: Vols. 22, 27, 29-38.

**R. T. Hill.**

Geological History of the Isthmus of Panama and Portions of Costa Rica, in vol. xxviii. of *Bulletin* of Museum of Comparative Zoology. Cambridge.

Geology and Physical Geography of Jamaica, in vol. xxxiv. of *Bulletin* of Museum of Comparative Zoology.

Complete sets of the above publications are greatly needed, as none of them are duplicated in the library of the American Institute of Electrical Engineers or in that of the American Society of Mechanical Engineers.

Please communicate on the above subject with R. W. Raymond, Chairman of the Library Committee, 29 W. 39th St., New York, N. Y.

## LIBRARY.

**AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.**

**AMERICAN SOCIETY OF MECHANICAL ENGINEERS.**

**AMERICAN INSTITUTE OF MINING ENGINEERS.**

The libraries of the above-named Societies are open from 9 A.M. to 9 P.M. on all week-days, except holidays, from September 1 to June 30, and from 9 A.M. to 6 P.M. during July and August.

### RULES.

For the protection and convenience of members, the following rules have been adopted:

The Secretary of each Society will, upon application, issue to any member of his Society in good standing a personal, non-transferable card, entitling him to the use of the Libraries in the alcoves of the Reading-Room.

This card, as well as any card of introduction given to a non-member, must be signed by the person receiving it, and surrendered at the desk at the time of its presentation. At every visit he must identify himself by signing his name in the registry.

Strangers who desire to enjoy the privilege of entering the alcoves are requested to present either letters of introduction from members, or cards, such as will be furnished upon application by the Secretary of each Society. The first two alcoves are free to all; and admission to the inside alcoves is given upon proper introduction.

The above rules apply to all persons except officers of the three Societies, personally known as such to the librarians.

The librarians are not permitted to lend to any person any catalogued pamphlet or volume, unless authorized in writing so to do by the Secretary or Chairman of the Library Committee of the Society to which the pamphlet or volume belongs.

Any person discovering a mutilation or defect in any book of the libraries is requested to report it to the librarian on duty.

**Accessions.**

From May 1 to June 30, 1908.

**American Association for the Advancement of Science.**

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

*Proceedings.* Vols. 56, 57. 8vo. New York, 1907.

**American Iron and Steel Association.**

AMERICAN IRON AND STEEL ASSOCIATION. *Directory to the Iron and Steel Works of the United States.* Seventeenth edition. Correct to March 1, 1908. 8vo. 500 p. Philadelphia, 1908.

[**SECRETARY'S NOTE.**—Though the veteran editor of this work has modestly omitted his name from the title-page, the initials at the end of the preface indicate that our old friend, J. M. Swank, is still at the helm, and that this new edition of the well-known summary which he has for so many years prepared carries with it the guaranty of completeness and accuracy which has become indissolubly associated with his name.

The size of this volume testifies to the enormous growth of our iron and steel industry since Mr. Swank became its official chronicler. But the duty of reporting the nature, capacity and ownership of American iron and steel works has been immensely increased by changes in ownership, as well as by alterations and enlargements of local establishments. This new demand has been met by Mr. Swank's intelligence, experience, historical memory, and indefatigable industry; and this latest product of his skill presents not only a complete picture of the present situation, but also the necessary clues to the recent developments of which it is a result. It is not only useful, but indispensable; and, within its sphere, it is not only easily first, but first without second.—R. W. R.]

**Bion J. Arnold.**

ARNOLD, B. J. *Capacity of the Subway of the Interborough Rapid Transit Company of New York City.* 50 p. il. pl. 8vo. New York, 1908. (Report No. 4, May 22, 1908.)

— *Subway Signal System.* 42 p. il. 8vo. New York, 1908. (Report No. 2.)

**Hans C. Behr.**

BEHR, H. C. *Some Suggestions for Carrying Out Power and Efficiency Tests on the Mine.* 12 p. n. p., 1908.

**Boston Society of Civil Engineers.**

BOSTON SOCIETY OF CIVIL ENGINEERS. *Constitution and By-Laws and List of Members,* June, 1908. 8vo. Boston, 1908.

**Canadian Mining Institute.**

CANADIAN MINING INSTITUTE. *List of Officers, Members, and Students,* May 1, 1908. 8vo. Montreal, 1908.

**John A. Church.**

BENJAMIN, PARK. *The Intellectual Rise in Electricity.* A History. 611 p. por. 8vo. New York, Appleton & Co., 1895.

CROLL, JAMES. *Climate and Time in Their Geological Relations.* xvi, 577 p. pl. 8vo. New York, Appleton & Co., 1875.

DANA, J. D. *Corals and Coral Islands.* 406 p. il. pl. 8vo. New York, Dodd & Mead, 1874.

DOUGLAS, S. H. and PRESCOTT, A. R. *Qualitative Chemical Analysis.* Ed. 2, revised. 254 p. 8vo. New York, Van Nostrand, 1876.

GAETZSCHMANN, MORIZ FERD. *Die Aufbereitung.* Atlas.

GRODDECK, A. VON. *Die Lehre von den Lagerstätten der Erze:* xii, 351 p. il. 8vo. Leipzig, 1879.

HAMILTON, SIR W. *Observations on Mount Vesuvius, Mount Etna, and Other Volcanoes.* iv, 179 p. pl., map. 8vo. London, 1774.

JAPAN—DEPARTMENT OF FINANCE. *Sixth Financial and Economic Annual of Japan,* 1906. 8vo. Tokyo, 1906.

LYELL, SIR CHARLES. *Principles of Geology.* Ed. 11. 2 vols. il. 8vo. New York, Appleton & Co., 1873-'74.

PAGE, DAVID. *Economic Geology.* xiv, 1, 336 p. il. pl. 8vo. Edinburgh-London, 1874.

PARK, MUNGO. *Journal of a Mission to the Interior of Africa in the Year 1805.* Ed. 2. xvii, 2, 373 p., map. 4to. London, 1815.

RICHTHOFFEN, F. F. VON. *China.* Vols. 1-2, 4, and Atlas. 4to. Berlin, 1877, '82, '83, '85.

RITTINGER, P. R. VON. *Lehrbuche der aufbereitungskunde. Erster nachtrag.* Atlas. 8vo and 4to. Berlin, 1870.

SCROPE, G. P. *Volcanoes, the Character of Their Phenomena, etc.* Ed. 2. v. p. il., map. 8vo. London, 1872.

SHATTUCK, G. B., Editor. *The Bahama Islands.* xxxii, 630 p. pl., maps. 8vo. New York, Macmillan Co., 1905.

STRICKLAND, W.M. *Reports on Canals, Railways, Roads, and Other Subjects Made to the Pennsylvania Society for the Promotion of Internal Improvement.* vi, 51 p. pl. Ob. 4to. Philadelphia, 1826.

**John A. Church.**

U. S.—GEOLOGICAL SURVEY. *Bulletin* No. 62. 8vo. Washington, 1890.

— *Monograph*. Vol. 5. 4to. Washington, 1883.

**A. A. Cole.**

COLE, A. A. *Temiskaming and Northern Ontario Railway Commission*. Report on Cobalt District for the Year 1907. 21 p. 8vo. Toronto, 1908.

**Cornell University.**

ASSOCIATION OF CIVIL ENGINEERS OF CORNELL UNIVERSITY.

*Transactions*. Vols. 1-5, 7-14, 1892-1897, 1899-1906. 8vo. Ithaca, 1893-1906.

*Cornell Civil Engineer*. Vol. 15, Nos. 1-4; Vol. 16, Nos. 1-5. 8vo. Ithaca, 1907-1908.

**Department of Colonization, Mines, and Fisheries of Quebec.**

QUEBEC—DEPARTMENT OF COLONIZATION, MINES, AND FISHERIES. *Mining Operations in the Province of Quebec*, 1907. 8vo. Quebec, 1908.

**Engineering and Mining Journal.**

GEORGIA—GEOLOGICAL SURVEY. *Bulletin* No. 14. 8vo. Atlanta, 1908.

GUARINI, EMILE. *Le Passé, le Présent et l'Avenir de la Télégraphie sans fil*. 192 p. il. 8vo. Paris, n. d.

IDAHO—STATE INSPECTOR OF MINES. *Annual Report of the Mining Industry*, 9th. 8vo. Boise, 1908.

INGALLS, W. R. *Lead and Zinc in the United States*. x, 368 p. il. pl. New York, Hill Publishing Co., 1908.

[SECRETARY'S NOTE.—This admirable book fills a space not heretofore occupied in our technical literature. As the preface informs us, it has been prepared at the request and with the aid of the Carnegie Institution, as a part of the Economic History of the United States which is to be published by that body. The occurrences of lead-ore in the United States and the history of their exploitation in the several States and Territories, together with an account of metallurgical progress and of changing commercial and industrial conditions, occupy Part I.; and Part II. contains similar information concerning the history and conditions of the American zinc industry.—R. W. R.]

NEW JERSEY—BUREAU OF STATISTICS OF LABOR AND INDUSTRIES. *Annual Report*, 30th. 8vo. Camden, 1908.

NOVA SCOTIA—DEPARTMENT OF MINES. *Report*, 1907. 8vo. Halifax, 1908.

**Engineering and Mining Journal.**

PETERS, FRANZ. *Thermoelemente und Thermosaulen.* vi, 184 p. 8vo. Halle a. S., 1908.

U. S.—AGRICULTURE, DEPARTMENT OF. *Experiment Station Record.* Vol. 19, No. 7. 8vo. Washington, 1908.

U. S.—GEOLOGICAL SURVEY. *Bulletin* Nos. 326, 329, 332, 336, 342. 8vo. Washington, 1907-'08.

— *Professional Paper* No. 55. 4to. Washington, 1907.

— *Water Supply and Irrigation Paper* Nos. 210, 213 215, 217, 218. 8vo. Washington, 1907-'08.

UNIVERSITY OF WISCONSIN. *Bulletin* Nos. 188, 193. 8vo. Madison, 1907-'08.

WEHNER, HEINRICH. *Das Innere der Erde und der Planeten.* iv, 74 p. 8vo. Freiberg i. S., 1908.

**Engineers' Club of St. Louis.**

ENGINEERS' CLUB OF ST. LOUIS. *Annual Bulletin*, 13th. 8vo. St. Louis, 1908.

**J. L. Harrington.**

HARRINGTON, J. L. *The Necessity for Individual Engineering Libraries and for Continuing Study after Graduation.* 24 p. 8vo. Kansas City, n. d.

**Herma Securities Company.**

DIETERICH, L. M. *The Evolution of the Automobile.* Ed. 2. 8vo. n. p., n. d.

— *Theory and Practice of the Dieterich Universal Drive Axle.* Ed. 2. 8vo. n. p., n.d.

**H. A. Hunicke.**

HUNICKE, H. A. *The Chemical Engineer.* 19 p. 8vo. St. Louis, n. d.

**Institution of Mining and Metallurgy.**

INSTITUTION OF MINING AND METALLURGY. *Bulletin* Nos. 44, 45. 8vo. London, 1908.

**Kelley Company.**

*Railroad Map and Industrial Map of the Birmingham District, Alabama.* n. d.

**Königlich Preussischen Geologischen Landesanstalt und Bergakademie zu Berlin.**

KÖNIGLICH PREUSSISCHEN GELOGISCHEN LANDESANSTALT UND BERGAKADEMIE ZU BERLIN. *Jahrbuch.* Vol. 25. 4to. Berlin, 1907.

**G. F. Kunz.**

KUNZ, G. F. *Gems and Precious Stones of Mexico.* 54 p. 4to. Mexico, 1907.

**Lehigh University.**

LEHIGH UNIVERSITY. *Register, 1907-1908.* 8vo. South Bethlehem, 1908.

**Lewis Institute.**

LEWIS INSTITUTE. *Bulletin Announcement of Courses for 1908-1909.* 8vo. Chicago, 1908.

**Manchester Geological and Mining Society.**

MANCHESTER GEOLOGICAL AND MINING SOCIETY. *Authors' and Subject Matter Index to the Transactions.* Vols. 1-28. 8vo. Manchester, 1908.

**Maryland Weather Service.**

MARYLAND WEATHER SERVICE. *Report.* Vol. 2. 4to. Baltimore, 1907.

**McGraw Publishing Company:**

ARMAGNAT, B. *The Theory, Design, and Construction of Induction Coils.* Translated and Edited by O. A. Kenyon. v, 216 p. il 8vo. New York, 1908. Price, \$2.00 net.

[SECRETARY'S NOTE.—MR. KENYON, already known as the editor and translator of Michalke's *Stray Currents from Electric Railways*, and Claudet's *Handbook of Mathematics*, has rendered a fresh, and still more important, service to electrical practice by contributing to our technical literature this treatise of a distinguished foreign authority, which deals intelligently and suggestively with the theory of mechanical and electrolytic interrupters, the secondary current, the construction and test of apparatus, and the uses of induction coils. The prefatory history of the subject is highly interesting; and the bibliography, which Mr. Kenyon has brought down to date from 1904, where the original author left it, is considerably more than an ordinary bibliography, because it comprises many critical estimates, summaries and analyses of the works named in it. While our American electrical experts are at least abreast—if not in the lead—of progress in that art, I know that the foremost of them are the most eagerly desirous of knowing what has been done in theory or practice, by their colleagues abroad. This book will be welcome to them for that reason, if for no other. But it must be added, in justice to the author, that he has not ignored American authorities. In fact, his bibliography begins with the article published by Prof. Joseph Henry in the *American Journal of Science*, in 1832.—R. W. R.]

**F. J. H. Merrill.**

MERRILL, F. J. H. *Mineral Resources of Sonora.* 23 p. il. 8vo. n. p., 1908.

**Michigan—Bureau of Labor and Industrial Statistics.**

MICHIGAN—INDUSTRIAL STATISTICS, BUREAU OF. *Annual Report, 25th.* 8vo. Lansing, 1908.

**Mining Society of Nova Scotia.**

MINING SOCIETY OF NOVA SCOTIA. *Journal.* Vol. 11. 8vo.  
Halifax, 1908.

**Minister of Mines of British Columbia.**

BRITISH COLUMBIA—MINISTER OF MINES. *Annual Report,*  
1907. 8vo. Victoria, 1908.

**Missouri—School of Mines and Metallurgy.**

MISSOURI—SCHOOL OF MINES AND METALLURGY. *Annual  
Catalogue, 37th, 1907–08.* 8vo. Rolla, 1908.

**Moonta School of Mines.**

MOONTA SCHOOL OF MINES. *Annual Report, 1907.* 8vo.  
Moonta, 1908.

**New Zealand—Registrar General's Office.**

*Report on the Results of a Census of the Colony of New  
Zealand, Taken for the Night of the 29th of April, 1906.*  
By E. J. von Dadelszen. vii, 163 p. 4to. Wellington,  
1908.

**Nova Scotia—Department of Mines.**

NOVA SCOTIA—MINES, DEPARTMENT OF. *Report, 1907.*  
8vo. Halifax, 1908.

**Pennsylvania Steel Co.**

*The Mayari and Daiquiri Iron-Ore Mines of the Spanish-  
American Iron Company.* 16 p. il. 4to. n. p., n. d.  
From articles published in the *Iron Age*, Aug. 15, 1907,  
and Apr. 8, 1908.

**Philadelphia Commercial Museums.**

MACFARLANE, J. J. *Foreign Trade of the United States for  
1907.* 28 p. il. 8vo. Philadelphia, 1908.

**Railway News Bureau.**

THOMPSON, SLASON. *Cost, Capitalization, and Estimated  
Value of American Railways.* Ed. 3, 177 p. il. 8vo.  
Chicago, 1908.

**Shelby Iron Company.**

SHELBY IRON COMPANY. *Report of the President, 1908.*  
8vo. Birmingham, Ala., 1908.

**Societa Toscana di Scienze Naturali.**

SOCIETA TOSCANA DI SCIENZE NATURALI. *Atti, Memorie.*  
Vol. 23. 8vo. Pisa, 1907.

**Julius Springer.**

HEISE, PROF. F. und HERBST, PROF. F. *Lehrbuch der  
Bergbaukunde, mit Besonderer Berücksichtigung des Stein-*

*kohlenbergbaus.* (Manual of the Art of Mining, with Special Reference to Coal Mining.) Vol. 1. xix, 694 p. il. 8vo. Berlin, 1908.

[SECRETARY'S NOTE.—Prof. Heise is the Director of the Mining School at Bochum, and Prof. Herbst is connected with the Technical High-School at Aachen, —two practical schools which have much to do with the mining industries of Westphalia, in the midst of which they have long flourished. This volume (to be followed by a second after about two years) treats of economic geology and ore-deposits (especially coal-formations); prospecting, boring, blasting, explosions, mechanical coal-cutting, stoping, sinking and drifting, ventilation and miner's lamps. It is chiefly confined, aside from elucidations of theory, to German practice, of which it presents a remarkably compact, yet clear and comprehensive, epitome. It is worthy of note that the 585 illustrations (two of which are colored plates) have evidently been prepared expressly for the book, and therefore have an agreeable uniformity of style, with the greater advantage besides, that they are not overloaded with superfluous or obscure details, such as are often found in engravings reduced from working-drawings, etc. These "schematic" illustrations really "illustrate" the text, without irrelevant and confusing additions.—R. W. R.]

### State Water Supply Commission of New York.

NEW YORK—STATE WATER SUPPLY COMMISSION. *Annual Report, 1st-3d.* 8vo. Albany, 1906—1908.

### Dr. Joseph Struthers.

REID, WHITELAW. *The "Practical Side" of American Education.* 24 p. 8vo. London, 1907.

U. S.—AGRICULTURE, DEPARTMENT OF. *Bureau of Forestry. Circular No. 139.*

*The Mayari and Daiquiri Iron-Ore Mines of the Spanish-American Iron Company.* 16 p. il. 4to. n. p., n. d.

### U. S.—Library of Congress.

U. S.—LIBRARY OF CONGRESS. *List of Works Relating to Deep Waterways from the Great Lakes to the Atlantic Ocean.* 59 p. 8vo. Washington, 1908.

### U. S.—Office of the Chief of Ordnance.

U. S.—ORDNANCE, DEPARTMENT OF. *Report of the Tests of Metals, 1907.* 8vo. Washington, 1908.

### U. S.—War Department—Office of the Chief of Engineers.

U. S.—CHIEF OF ENGINEERS, OFFICE OF. *Annual Report, 1906, 1907.* 8vo. Washington, 1906—1907.

### Washburn College.

WASHBURN COLLEGE. *General Catalogue, 1907—1908.* 8vo. Topeka, 1908.

**Western University of Pennsylvania.**

WESTERN UNIVERSITY OF PENNSYLVANIA. *Bulletin of the School of Mines.* February, 1908. 8vo. n. p., 1908.

**John Wiley & Sons.**

BUTLER, G. M. *A Pocket Handbook of Minerals.* Designed for Use in the Field or Class Room, with Little Reference to Chemical Tests. ix, 298 p. il., tab. 8vo. New York, 1908. Price, \$3.00.

[SECRETARY'S NOTE.—This very handsome and compendious pocket-manual is designed for the convenience of students and field-workers, as a preliminary substitute for the consultation of more elaborate treatises, and especially to facilitate the recognition of mineral species according to *habitus* and physical characteristics, without waiting for the results of chemical analysis. All those who, like myself, have been trained in European schools, and also (as I think) all who have studied in American schools, will remember that the best teachers of mineralogy relatively despised the report of the chemical laboratory, and insisted that their pupils should be able, by practicable field-tests, to recognize with practical certainty, at least in massive or crystalline aggregates, most mineral species. In my judgment, this is still a *desideratum*; and Mr. Butler's book is a convenient aid to it. It contains, besides the usual description of physical characteristics, some useful tables of the present value of metals and minerals; a limited but helpful glossary, and an index. There are also many illustrations, of which the diagrams of crystal forms are directly serviceable, as well as ornamental.—R. W. R.]

SNOW, C. H. *The Principal Species of Wood.* Ed. 2. xvi, 212 p., il. pl. 8vo. New York, 1908. Price, \$3.50.

[SECRETARY'S NOTE.—This eminently practical treatise by Prof. Snow, of New York University, was issued first in 1903; and the author has taken advantage of the demand for a second edition to revise the work throughout, entirely re-writing some sections of it, and adding more than four hundred titles to the index. Prof. Snow is Dean of the School of Applied Science of his University; has been for many years an honored member of this Institute, and has been since 1905 a member of the Board of Directors controlling its corporate affairs. The work he has done as a teacher and administrator, together with his contributions to technical literature, will explain the recognition which he has won as a representative, both of practice and of theory. This manual, though not professing to be more than a compilation, is really more than that, because its contents have been selected and arranged with an intelligent perception of the needs of those students and readers for whom it has been designed—namely, "those who are not foresters or botanists, but who use woods, or desire knowledge of their distinguishing properties." The information thus given comprises much more than the usual data concerning the transverse or tensile strength of each species described. The present edition differs so greatly from the first one as to be almost a new book. Many corrections have been made in it; some of the sections have been wholly re-written; 400 new names have been added to the index; and the result is that the new edition is a practically complete manual, whereas its predecessor was but a meritorious and promising attempt in that direction.—R. W. R.]

**David Williams Company.**

*The Iron Age Directory*, 1908. 8vo. New York, 1908.

**Wisconsin—Geological and Natural History Survey.**

WISCONSIN—GEOLOGICAL AND NATURAL HISTORY SURVEY.

*Road Pamphlet*. Nos. 1-4. 12mo. Madison, 1907.

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*Centralblatt für Mineralogie*. 1903-1906. 8vo. Stuttgart, 1903-'06.

*Coal and Metal Miners' Pocketbook*. Ed. 9. 8vo. Scranton, 1907.

HARBORD, E. W. *Metallurgy of Steel*. Ed. 3, xxiv, 770 p. London, 1907.

*Neues Jahrbuch für Mineralogie*, etc. 1887-1906. 8vo. Stuttgart, 1887-1906.

— *Beilage Bande*. 5-19. 1887-1904. 8vo. Stuttgart, 1887-1904.

PLATTNER, C. F. *Probierkunst mit dem Löhhohre*. xvi, 515 p. il. 8vo. Leipzig, 1907.

*Van Nostrand's Chemical Annual*, 1907. Edited by J. C. Olsen. 8vo. New York, 1907.

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**NEW EXCHANGES.**

*American Industries*. Bi-Weekly. Vol. 7, No. 7-date. 4to. New York, 1908-date.

*Arkiv fur Kemi*. Irregular. 1908-date. Stockholm, 1908-date.

*Die Turbine*. Year 4, No. 17-date. 4to. Berlin, 1908-date.

*Oil Investors' Journal*. Semi-Monthly. Vol. 7-date. 8vo. Kansas City, 1908-date.

*Organ des "Verein der Bohrtechniker."* Bi-Weekly. Year 5-date. 4to. Wien, 1908-date.

*Vulcan*. Weekly. Year 8, No. 24-date. 4to. Frankfurt a.M. 1908-date.

**TRADE CATALOGUES.**

Realizing the value of trade catalogues in a technical library, the Library Committee of the American Institute of Mining Engineers has signified its approval of a plan to strengthen the library along this line. Manufacturers are therefore

asked to place the Library of the American Institute of Mining Engineers on their regular mailing-lists for Trade Catalogues on Metallurgical and Mining Machinery, Mine and Miners' Supplies, Metallurgical Laboratory Equipments, Assayers' and Chemists' Supplies, etc., and also Technical Industrial Catalogues.

All contributions will be acknowledged in the *Bi-Monthly Bulletin*.

**AERO PULVERIZER COMPANY**, 90 West St., New York, N. Y.  
Pulverized Fuel Combustion. (*Bulletin* Nos. 11, 12, 1907-'08.)

**CYCLONE DRILL COMPANY**, Orrville, Ohio. *The Drill Hole*. Vol. 2, No. 4. April, 1908.

**ENGINEERING RECORD**. Directory of Manufacturers of and Dealers in Engineers' and Contractors' Machinery and Supplies. 1908 edition. New York, 1908.

**GOLDSCHMIDT THERMIT COMPANY**, 90 West St., New York, N. Y. *Reactions*. Second quarter, 1908. 8vo. New York, 1908.

**JACKSON DRILL AND MANUFACTURING COMPANY**, 68 Broad St., New York, N. Y. The Improved Jackson Hand-Power Rock-Drill (*Bulletin* No. 18, 1908).

**JEFFREY MANUFACTURING COMPANY**, Columbus, Ohio. Jeffrey Mine Equipment.

— Jeffrey Centrifugal Fan for Mine Ventilation. (Catalogue No. 26, 1908.)

**KNOWLES STEAM PUMP WORKS**, 114 Liberty St., New York, N. Y. Boiler-Feed and Tank-Pumps. (*Bulletin* K 809.)

— Duplex Compound Condensing Plunger Pump. (*Bulletin* K 80.)

— Knowles Express Pump. (*Bulletin* K 73.)

— Palmer Special Sinking Pump.

— Special Duplex Center-Packed Outside Plunger Pumps. (*Bulletin* K 95.)

— Triple Power Pumps. (*Bulletin* B 72.)

**J. G. LEYNER ENGINEERING WORKS CO.**, Littleton, Colo. Steel Sharpening Apparatus. (*Bulletin* No. 514.)

**MASSACHUSETTS BELTING COMPANY**, 207 Congress St., Boston, Mass. Patented Combination Belting, Flat Transmission and Hoisting Rope.

PNEUMELECTRIC MACHINE COMPANY, Syracuse, N. Y. Electric Coal Puncher. 23 p. il. 8vo. Syracuse, n. d.

SCULLY STEEL AND IRON COMPANY, Chicago, Ill. Stock List. May and June, 1908.

SIMON CARVES, LTD., 20 Mount St., Manchester, England. Coal Washing and Screening Plants (Baum's System). 8vo. Manchester, n. d.

STURTEVANT MILL COMPANY, Boston, Mass. Sturtevant Plate Steel Crushers, 1907.

B. F. STURTEVANT COMPANY, Hyde Park, Mass. Generating Sets with Vertical Compound Engines, 150-500 kw. (*Bulletin No. 156, Engineering Ser., 1908.*)

SULLIVAN MACHINERY COMPANY, Chicago, Ill. The Sullivan Hammer Drills. (*Bulletin No. 60 B, June, 1908.*)

— Sullivan Stone Channelers. (Catalogue 61.)

VULCANITE PORTLAND CEMENT COMPANY, Flatiron Building, New York, N. Y. Crazing or Hair Cracks on Concrete Surface, by A. Moyer.

## NEW MEMBERS.

The following list comprises the names of those persons elected as members or associates, who accepted election during May and June, 1908:

## MEMBERS.

|                        |                                |
|------------------------|--------------------------------|
| William H. Bainbridge, | Searchlight, Nev.              |
| William N. Brown,      | Gainesville, Va.               |
| Willis S. Caypless,    | Denver, Colo.                  |
| William B. Clark,      | Baltimore, Md.                 |
| Manuel H. de Hora,     | Butte, Mont.                   |
| William H. Goodchild,  | Finchley, Middlesex, England.  |
| Heinrich F. Grondijs,  | Oruro, Bolivia, S. America.    |
| William Harris,        | Seattle, Wash.                 |
| Harry S. Harrop,       | Wilkinsburg, Pa.               |
| George Hohagen,        | Potosi, Bolivia, S. America.   |
| Frederick A. Horswill, | Oakland, Cal.                  |
| Frederick J. Horswill, | Oakland, Cal.                  |
| Frederick H. Jackson,  | Indé, Durango, Mex.            |
| Weston Jenkins, Jr.,   | Columbia, Pa.                  |
| Arthur L. Kelley,      | Tonopah, Nev.                  |
| Martin H. Kilgour,     | East Orange, N. J.             |
| Joseph R. Lashbrooke,  | Grass Valley, Cal.             |
| Robert B. Law,         | Bangkok, Siam.                 |
| Alfred M. Mackilligin, | Tarkwa, West Africa.           |
| Nathan H. Mannakee,    | Williamson, W. Va.             |
| Philip L. Marston,     | Tonopah, Nev.                  |
| George E. Montandon,   | Graneros, Chile, S. America.   |
| Martin Munroe,         | Murulidih, Bengal, India.      |
| Frederic C. Paine,     | Sonoma, Cal.                   |
| Robert S. Porter,      | Stone Cañon, Cal.              |
| Robert S. Reid,        | Corocoro, Bolivia, S. America. |
| Hallet R. Robbins,     | Albany, N. Y.                  |
| Lee H. Skeels,         | Urique, Chihuahua, Mex.        |
| Lloyd B. Smith,        | State College, Pa.             |
| John G. Smyth,         | Fairmont, W. Va.               |
| Charles C. Swartz,     | South Norwalk, Conn.           |
| William J. Watson,     | Ladysmith, B. C., Can.         |

## ASSOCIATES.

|                        |                      |
|------------------------|----------------------|
| Carl Brewer,           | Ishpeming, Mich.     |
| R. Gordon Chaney, Jr., | Cripple Creek, Colo. |
| John M. Clark,         | Toronto, Can.        |

## CANDIDATES FOR MEMBERSHIP.

The following persons have been proposed for election as members or associates of the Institute during May and June, 1908. Their names are published for the information of members and associates, from whom the Committee on Membership earnestly invites confidential communications, favorable or unfavorable, concerning these candidates. A sufficient period (varying in the discretion of the Committee, according to the residence of the candidate) will be allowed for the reception of such communications, before any action upon these names by the Committee. After the lapse of this period, the Committee will recommend action by the Council, which has the power of final election.

### MEMBERS.

|  |                                     |
|--|-------------------------------------|
| James Archbald, Jr., . . . . .         | Pottsville, Pa.                     |
| Charles John Seymour Baker, . . . . .  | London, England.                    |
| Harvey Bassler, . . . . .              | Myerstown, Pa.                      |
| Horace A. Beale, Jr., . . . . .        | Parkesburg, Pa.                     |
| Paul K. Brill, . . . . .               | Brooklyn, N. Y.                     |
| Robert Leland Brown, . . . . .         | Auburn, Ala.                        |
| Walter C. Buchanan, . . . . .          | San Luis de la Paz, Guayaquil, Mex. |
| Otto Cornelius Burkhart, . . . . .     | Bethlehem, Pa.                      |
| Horace Herbert Clark, . . . . .        | Chicago, Ill.                       |
| Clare Lorimer Colburn, . . . . .       | Denver, Colo.                       |
| Charles Norton Crary, . . . . .        | Valdez, Alaska.                     |
| Murray F. Crossette, . . . . .         | Chicago, Ill.                       |
| George H. Dickson, . . . . .           | Coleman, Alberta, Can.              |
| John Fenwick Dickson, . . . . .        | Houston, Texas.                     |
| Clarence Gibson Dresser, . . . . .     | Salt Lake City, Utah.               |
| Joseph F. Erdlets, Jr., . . . . .      | Yerington, Nev.                     |
| Toranosuke Furukawa, . . . . .         | Tokio, Japan.                       |
| William V. Griffith, . . . . .         | La Fundicion, Peru, S. America.     |
| Henry Theodore Hinrichsen, . . . . .   | Lota, Chile, S. America.            |
| John Frederick Kramer, . . . . .       | Robesonia, Pa.                      |
| Henry Minton Lewis, Jr., . . . . .     | New York, N. Y.                     |
| James H. McManaman, . . . . .          | Careyville, Tenn.                   |
| Anthony John McMillan, . . . . .       | Rossland, B. C., Can.               |
| Prosper Auguste Maignen, . . . . .     | Philadelphia, Pa.                   |
| A. W. Martin, . . . . .                | Carrizal, Chile, S. America.        |
| Stephen Elliott Puckette, . . . . .    | Darbyville, Va.                     |
| Jonathan Parker Snow, . . . . .        | Boston, Mass.                       |
| Washington B. Vanderlip, . . . . .     | New York, N. Y.                     |
| Wilfred Benjamin Wainwright, . . . . . | Los Angeles, Cal.                   |
| Joseph E. White, . . . . .             | Searchlight, Nev.                   |

### ASSOCIATES.

|                                   |                 |
|-----------------------------------|-----------------|
| Charles Goodman Ewing, . . . . .  | St. Louis, Mo.  |
| Frank A. Gleason, . . . . .       | Scranton, Pa.   |
| A. Bell Malcomson, Jr., . . . . . | Freeport, N. Y. |

## CHANGES OF ADDRESS OF MEMBERS.

The following changes of address of members have been received at the Secretary's office during the period of May 1 to July 1, 1908. This list, together with the lists in *Bi-Monthly Bulletin*, No. 20, March, and No. 21, May, 1908, therefore, supplements the annual list of members corrected to Jan. 1, 1908, and brings it up to the date of July 1, 1908. The names of members who have accepted election during May and June, 1908 (new members), are printed in *italics*.

By a simple method of cutting out these names and addresses, and pasting them directly over the corresponding names in the annual list of members, the record can be kept practically up to date and the value of the list correspondingly increased. For this purpose the changes of address have been printed only on one side of the page. The names of new members, being in *italics*, are readily distinguished from the others, and can be pasted in approximate alphabetical order on the margins of the pages of the list.

ADAMS, GEORGE I., Geol., Bureau of Mines.....Manila, Philippine Islands.  
ALABASTER, RUPERT C., Genl. Mgr., Queensland Exploration Co.,  
Cloncurry, Queensland, Australia.  
APLIN, WILLIAM, Instructor in Chemistry, etc., Moonta School of Mines,  
Moonta, So. Australia.  
ASHMORE, G. PERCY, Cons. Min. Engr., The South West Africa Co.,  
Grootfontein via Schwakopmund, S. W. Africa.  
\*Bainbridge, William H., Mine Supt.....Searchlight, Nev. '08.  
BARTLETT, JOHN R. ....Rooms 11 and 12, 48 E. Granite St., Butte, Mont.  
BARTOCCINI, ASTOLFO, Contracting Engr.....214 E. 90th St., New York, N. Y.  
BEATTY, A. CHESTER.....165 Broadway, New York, N. Y.  
BODDINGTON, HENRY D.....23 Sketty Road, Enfield, Middlesex, England.  
BOHLER, RICHARD F. ....I Elisabethstrasse 12, Vienna, Austria.  
BRADEN, WILLIAM.....Room 1813, 165 Broadway, New York, N. Y.  
BRETHERTON, S. E., Cons. Min. and Met Engr., Bretherton Metallurgical Co.,  
532 Commercial St., San Francisco, Cal.  
BRETHERTON, WALLACE B., Assayer and Chem., Bretherton Metallurgical Co.,  
532 Commercial St., San Francisco, Cal.  
†Brewer, Carl, Min. Engr., Care Cleveland-Cliffs Iron Co., Ishpeming, Mich. '08.  
BRITT, RICHARD H.....Western Nevada Copper Co., Yerington, Nev.  
\*Brown, William N., Min. Engr.....Gainesville, Va. '08.  
BURNAND, ALPHONSE A.....1001 Central Bldg., Los Angeles, Cal.



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| CALDWELL, WILLIAM A.....  | Instructed to hold all mail.                               |
| *Caypless, Willis S., Min. Engr.....                                  | 1035 Logan Ave., Denver, Col. '08.                         |
| †Chaney, R. Gordon, Jr., Student.....                                 | El Paso Mine, Cripple Creek, Col. '08.                     |
| CHAPLIN, GEORGE P., Care Arthur Stegman, Barranquilla, Colombia,      | So. America.   |
| CHAPMAN, JAMES E.....   | Bonanza, Zac., Mexico.                                     |
| CHASE, FRANK D.....   | Dedham, Mass.  |
| CHISHOLM, JOHN, Resident Engr., The Anglo-Russian Platinum Co., Ltd., | Nijni Turinsk, Govt. of Perm, Russia.                      |
| CHURCH, ALBERT K.....   | Hampton, N. H.   |
| †Clark, John M., Barrister.....                                       | 16 King St., West, Toronto, Ont., Canada. '08.             |
| CLARK, MAURICE, Min. Engr.....  | Apartado 105, Oaxaca, Oax., Mexico.                        |
| *Clark, William B., Geol.....   | Johns Hopkins University, Baltimore, Md. '08.              |
| COLCOED, FRANK F.....   | U. S. Metals Refining Co., Chrome, N. J.                   |
| CORBUS, A. W.....   | 645 Georgia St., Vallejo, Cal.                             |
| CRAWFORD, HENRY E.....  | 344 Bradbury Bldg., Los Angeles, Cal.                      |
| CRAWFORD, WALTER H., Vanderbilt Bldg., 315 Fourth Ave., North,        | Nashville, Tenn.   |
| CREMER, FELIX.....  | Cerro Colorado Mining Co., Cerro Colorado, Sonora, Mexico. |
| DENBY, WYTHE.....   | Mgr. Hewitt Mining Co., Silverton, B. C., Canada.          |
| DERBY, CHARLES C.....   | New Almaden, Cal.  |
| DOWE, JOHN H.....   | Nagybanya, Hungary.  |
| DRUMMOND, THOMAS R.....   | Care Newhouse Mines & Smelters, Newhouse, Utah.            |
| DRURY, WALTER M.....  | Minas Tecolotes, Santa Barbara, Chih., Mexico.             |
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| EWING, FREDERIC.....  | Copper Mines Co., Ruth, White Pine Co., Nev.               |
| FINK, WILLIAM N.....  | San Toy Mining Co., Santa Eulalia, Chih., Mexico.          |
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|---|---|
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| UPHAM, W. E.  | 101 Bleecker St., Toronto, Ont., Canada.              |
| VIVIAN, GEORGE G., Met.   | Pittsburgh & Montana Copper Co., Butte, Mont.         |
| WALKER, ARTHUR L.   | School of Mines, Columbia University, New York, N. Y. |
| WALLACE, ROBERT, Agent, Anganguero Unit, Am. Smeltg. & Refg. Co., | Anganguero, Mich., Mexico.                            |
| WARNE, HERBERT H., Min. Engr.                                     | Apartado 121, Mexico City, Mexico.                    |
| * Watson, William J., Smelter Mgr., Care Tyee Copper Co.,         | Ladysmith, B. C., Canada. '08.                        |
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| WHITMAN, PHILIP R.  | Care Indé Gold Mining Co., Indé, Durango, Mexico.     |
| WILKINSON, WILLIAM F.   | 43 Threadneedle St., London, E. C., England.          |
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| WRIGHT, FREDERIC E.   | Geophysical Laboratory, Washington, D. C.             |
| WRIGHT, HERBERT B., Engr., Tazewell Div., Pocahontas              | Consolidated Collieries Co., Inc., Pocahontas, Va.    |

## ADDRESSES OF MEMBERS AND ASSOCIATES WANTED.

| Name.                          | Last Address on Records, from which Mail has been Returned. |
|--------------------------------|---|
| <b>Alexander, George E.</b>    | Sparta, Ore.  |
| <b>Barnardo, William S. E.</b> | Surbiton, Surrey, England.                                  |
| <b>Bassett, Thomas B.</b>      | Cumpas, Sonora, Mexico.                                     |
| <b>Bell, Stanislaus C. N.</b>  | Brisbane, Queensland, Australia.                            |
| <b>Bellam, Henry L.</b>        | Reno, Nev.  |
| <b>Berry, J. F.</b>            | East Rand, Transvaal, So. Africa.                           |
| <b>Bradley, Richard J. H.</b>  | 15 William St., New York, N. Y.                             |
| <b>Bruce, Thomas C.</b>        | Johannesburg, Transvaal, So. Africa.                        |
| <b>Burhans, Harry H.</b>       | Michigan College of Mines, Houghton, Mich.                  |
| <b>Cleland, George A.</b>      | Tonopah, Nev.   |
| <b>Dikeman, J. M.</b>          | Rough and Ready, Cal.                                       |
| <b>Dougherty, Clarence E.</b>  | 41 Wall St., New York, N. Y.                                |
| <b>Durell, Charles T.</b>      | Cima, Cal.  |
| <b>Edwards, Henry W.</b>       | Silver City, New Mexico.                                    |
| <b>Edwards, William S.</b>     | 74 Broadway, New York, N. Y.                                |
| <b>Ekberg, Benjamin P.</b>     | Johannesburg, Transvaal, So. Africa.                        |
| <b>Fleming, William L.</b>     | Springdale, Wash.   |
| <b>Foster, Floyd J.</b>        | Monterey, Mexico.   |
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| <b>Jackson, Byron N.</b>       | Milton, Cal.  |
| <b>Jewett, Elliot C.</b>       | 2918 Morgan St., St. Louis, Mo.                             |
| <b>Jones, Edward H.</b>        | Globe, Ariz.  |
| <b>Kelley, Walter S.</b>       | Dooly Block, Salt Lake City, Utah.                          |
| <b>Lamb, Robert B.</b>         | Kendall, Mont.  |
| <b>Lukis, E. duB.</b>          | Ica, Peru, So. America.                                     |
| <b>Mueller, Henry C.</b>       | General Delivery, San Francisco, Cal.                       |
| <b>Palacios, Jose G.</b>       | Monterey, N. L., Mexico.                                    |
| <b>Pickard, Thomas D.</b>      | Hedley, B. C., Canada.                                      |
| <b>Pollon, Howard A.</b>       | Snowden, Cal.   |
| <b>Reisinger, Paul</b>         | Great Northern Ry. Co., Minot, N. D.                        |
| <b>Roberts, Fred C.</b>        | Crystal Falls, Mich.  |
| <b>Robertson, Horace P.</b>    | El Oro, Mexico.   |
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| <b>Shaw, Clarence L.</b>       | Ely, Nevada.  |
| <b>Thomas, George W.</b>       | Exposed Treasure Mining Co., Mojave, Cal.                   |
| <b>Thomas, James A.</b>        | 115 New Montgomery St., San Francisco, Cal.                 |
| <b>Townsend, Neville F.</b>    | Le Roi Mine, Rossland, B. C., Canada.                       |
| <b>Vaux, Charles A.</b>        | P. O. Box 80, East Rand, So. Africa.                        |
| <b>Watson, Ralph W.</b>        | 122 E. S. Temple St., Salt Lake City, Utah.                 |
| <b>Wolfe, Burton L.</b>        | Ely, Nev.   |
| <b>York, James E.</b>          | 1811 Albemarle Road, Flatbush, N. Y.                        |
| <b>Young, Frederick E.</b>     | Howe Sound, via Vancouver, B. C., Canada.                   |

## NECROLOGY.

The deaths of the following members and associate have been reported to the Secretary's office during May and June, 1908:

| Date of<br>Election. | Name.                                      | Date of Decease:  |
|----------------------|--|-------------------|
| 1887.                | *L. U. Colbath, . . . . .                  | May 26, 1908.     |
| 1901.                | †Sterling, B. Cox, . . . . .               | May 22, 1908.     |
| 1898.                | *Alfred E. Jessup, . . . . .               | November —, 1907. |
| 1906.                | *E. G. N. North, . . . . .                 | March 29, 1908.   |
| 1885.                | *Hon. Prof. Dr. Hermann Wedding, . . . . . | May 6, 1908.      |
| 1895.                | *William S. Yeates, . . . . .              | Feb. 18, 1908.    |

## Biographical Notices.

*Bi-Monthly Bulletin*, No. 22, July, 1908.

THE following paragraphs comprise such information as the Secretary has been able to obtain concerning the members and associates whose deaths have been reported. Further particulars or corrections of errors, and biographical data concerning deceased members or associates not already noticed in this way, are solicited.

*Edward Descou Chester* was born at Penge, near London, England, Aug. 4, 1857. He received his education at the school of the Merchant Tailors' Guild in London, after leaving which he began practical work with the firm of Burt, Boulton & Hayward at Silvertown, London, subsequently studying for two years at the Royal School of Mines, South Kensington, and then going to Glasgow, where he was engaged for a year in research-work.

In 1880 he went to Venezuela as assistant superintendent of the New Chile mine, where he gained a knowledge of practice in mining engineering which largely influenced his later career. No doubt one result of this experience was his return to London, after his term of service was ended, and another course of study at the Royal School of Mines. With this additional

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\* Member.

† Associate.

preparation, he went to South Africa in 1883, as manager of an important mining company, projected by the late Col. McMurdo. At that time the Witwatersrand was unknown as a gold district, and mining was confined to the eastern border of the South African Republic; Piggs' Peak, the Sheba, and other mines being the objects of attention, with Barberton as a center. Realizing the future importance of gold-mining in South Africa, Mr. Chester opened at Barberton in 1884 an office as consulting engineer. He soon began to introduce at the mines with which he was connected American methods and machinery, both of which he had learned to value during his experience in Venezuela. With this purpose in view, he visited Chicago, and secured from Fraser & Chalmers and their allied companies an exclusive agency for their mining and metallurgical machinery in South Africa—then an almost unknown region.

Soon after, in 1886, the first discovery of gold was made on the bleak plateau of the Witwatersrand. The original camp was called Marshall's Township, but its boundaries were soon extended to the north, and the mushroom city received the official name of Johannesburg. Mr. Chester was soon on the spot. Mining was started along the outcrop as quickly as machinery could be hurried up—no easy matter when the nearest railway terminus was some 200 miles away. One of the leading companies was the Langlaagte Estate, founded by J. B. Robinson, of Kimberley fame; and Mr. Chester was appointed its consulting engineer—a position which he soon resigned, finding that his time was fully occupied with the importation and erection of machinery.

In looking back twenty years it now seems difficult to believe that a violent controversy raged as to the nature and permanence of the gold-bearing rock. Opinion was divided as to whether the conglomerate, which soon received the Dutch nickname of "blanket," would be found in depth, and if so whether it would carry gold. It was generally regarded and spoken of as a "reef," and the visionaries who dreamed of "deep levels" did not carry their most sanguine expectations many hundred yards from the outcrop. But Mr. Chester's geological training led him to conclude that the so-called "reef" was, in fact, an upthrust sedimentary deposit, which

might be expected to carry gold in depth as much as at the surface. Accordingly, he lost no time in opening an office on the new fields, in partnership with Mr. Gibb, leaving a branch to be maintained at Barberton.

The expansion of the Rand gold-fields and their connection with the railway systems of the Cape, Natal, and Delagoa bay, caused his business to grow by leaps and bounds; and the name of Edward Chester & Co. became a household word. The firm did not confine itself to the supply of machinery, but also undertook large contracts for erection. Mr. Chester also formed the Chester Diamond Drilling Co., which had much to do with the development of the deep levels. Some of the deepest bore-holes in the world were made under his supervision. He established also an office in London; a branch at Port Elizabeth, in the Cape Colony, for receiving and forwarding machinery; later (when Rhodesia had been reached by the railway) a branch at Bulawayo; and, finally, a branch at Kalgoorlie, in Western Australia.

Concerning this part of Mr. Chester's career, Mr. William J. Chalmers, in a letter to the Secretary, writes:

"Many years ago, Mr. Chester was the sales agent in Venezuela for Fraser & Chalmers; and when the mining excitement first broke out in Africa, he became the Resident Agent for the Transvaal and the Cape Colony of Fraser & Chalmers, Chicago, and later for Fraser & Chalmers, Ltd., London. He was successful in selling the first large stamp-mill introduced into Africa. His first order to Fraser & Chalmers was for one 60-stamp and one 120-stamp mill. During the six or seven years of the Transvaal excitement, his orders amounted to several million dollars."

Unfortunately, not content with the large business which he had thus built up as an agent and engineer, Mr. Chester severed his connection with American manufacturers, and, in 1898, established similar works of his own at Renfrew, Scotland. The enterprise failed, by reason of the outbreak of the war in South Africa, which suddenly closed the principal market for its products.

In his endeavor to find another field, he secured and successfully executed a contract for the whole of the pumping-machinery of the new water-works of Amsterdam; but such outside enterprises could not counterbalance the effect of the war and the business depression which followed it. Mr. Chester's

company went into liquidation; and he resumed his private practice as a consulting engineer. In February, 1906, he established himself at Salisbury, Rhodesia, where he continued his professional work until his death, Nov. 29, 1907.

Mr. Chester became a member of this Institute in 1890, and was also a member of leading technical societies in England. He published several papers on the reduction of ores, and was the first to prove in practice the advantage of certain proposed improvements in the method of stamp-milling on the Rand.

His business associates characterize him as competent and trustworthy, and his personal friends lament the loss of a friend, "large-minded, warm-hearted, and generous to a fault."

*Lemuel U. Colbath* was born in Wayne county, New York, Mar. 30, 1832. During his youth his family moved to Lima, Ohio, where he acquired his early education. In 1854 he emigrated to California, and engaged in mining, first in Eldorado county and afterwards at Volcano, Amador county, and at Grass Valley. In 1860 he went to Virginia City, Nevada, where he became superintendent of the Challenge and afterwards of the Kentuck Mining Co. After eight years in Virginia City, he spent two years at South Pass City, Wyoming, and in 1870 established at Salt Lake City, Utah, the residence and professional headquarters which he maintained until his death, May 26, 1908.

Mr. Colbath belonged to a peculiarly American class of mining engineers, which it is difficult to define and estimate—men who learned their business in the hard school of practice, and thus came to know more than they could formally explain; men who could judge the value of a mine by a sort of acquired intuition, and upon whose judgment other people, who knew them, were willing to risk their money; men who could encounter and overcome engineering difficulties with uninstructed but invincible inventive audacity. Mr. Colbath was a trusted associate of R. C. Chambers, especially in the acquisition and development of the famous Ontario mine at Park City, Utah, the management of which reflected high credit upon his skill. He was also, at different times, president or director of many mining corporations.

Mr. Colbath became a member of the Institute in 1887; and

many of its members still recall with pleasure the generous hospitality and intelligent guidance received from him at the Ontario mine in July of that year. He was personally regarded with high esteem by all who knew him.

*John Thomas Conner* was born, Nov. 1, 1836, in Philadelphia, Pa. While still a young man he joined in the rush to the new gold-fields at Pike's Peak in Colorado, and was occupied in mining there until the spring of 1863, when reports of rich discoveries in the Northwest, near what is now Bannack, Mont., drew him to that remote region. He soon removed to Varina, now Virginia City, Mont., where he was engaged in successful mining for many years. During 1894-5 he was President of the Society of Montana Pioneers. At the time of his death, which occurred Mar. 17, 1908, he was a Police Commissioner of the city of Helena. He joined the Institute in 1900.

*Robert J. Forsythe* was born, Sept. 5, 1869, at Braintree, Mass. After studying in the local high school and the Thayer Academy he entered Harvard University, where he was graduated in 1894. In 1895 he received the degree of M.A., and for three years remained at Harvard as Instructor in Metallurgy. Subsequently he had practical experience in the open hearth and blast-furnace departments of the Pennsylvania Steel Co., at Steelton, Pa., and the Tidewater Steel Co., at Chester, Pa. At the time of his death, May 23, 1907, his book, *The Blast-Furnace and the Manufacture of Pig-Iron*, was in proof. It has since been published. He joined this Institute in 1896.

*Alfred Emerson Jessup* was born, June 5, 1871, at Brooklyn, N. Y. After completing his preparatory education he entered Lehigh University, and graduated with the degree of B.S. in 1892. During 1892-93 he studied at Freiberg, Saxony. In 1894 he took a commercial position in Boston, and remained there until 1898, in which year he became assistant superintendent of blast-furnaces for the Maryland Steel Co., at Sparrow's Point, Md. In 1900 he became Engineer of Tests and Analytical Chemist to the U. S. Treasury Department at Washington, D. C. Here he remained until 1903, when he went to China, as Assayer and Analytical Chemist of the Imperial Mint at Tientsin. Mr. Jessup joined the Institute in 1898, and was

a member of the Iron and Steel Institute, London; the American Chemical Society; the Society of Chemical Industry, and the Cosmos Club, of Washington. He died in November, 1907.

*Edwin Gordon Niven North* was born, July 24, 1869, in London, England, and received his education at St. Saviour's School, Southwark. In 1884 he was articled to E. R. Southby, an analytical chemist. During 1885-88 he was employed as assistant chemist and analyst with Burgoyne, Burbridges, Cyriax & Farries. In 1888 he entered the employ of the Rio Tinto Company. After about a year in the London laboratory of this company he spent twelve years in their laboratory and works at Rio Tinto, Spain. During the later years of his employment there he had charge of the converting-plant. After severing his connection with this company he spent a year in special work for the Peña Copper Mines, Ltd., and another year as resident manager with the United Mercury Mines of Granada. Returning to England in the spring of 1905, he was employed by the Spassky Copper Mine, Ltd., to take charge of the smelting-plant of that company at Akmolinsk, Siberia.

It was in the Bessemer house of this company that he met an untimely death. The settler of the matte-remelting cupola collapsed; and he was overwhelmed in the molten metal. The accident occurred Mar. 27, and he died Mar. 29, 1908.

He was a skilled metallurgist, devoted to his work, and was the patentee for a method of eliminating arsenic from copper-precipitate. His character was unimpeachable, his loyalty unquestioned, and he was loved and is deeply deplored by his friends and fellow-workers. He joined this Institute in 1906.

*William Smith Yeates* was born in Murfreesboro, N. C., Dec. 15, 1856, and graduated at Emory and Henry College, Va., in 1878. In 1879 he was employed on the U. S. Fish Commission, and in 1880-81 in the Fisheries Division of the 10th U. S. Census. In the winter of 1880-81 he became Assistant in Mineralogy to Dr. George A. Hawes, then recently appointed Curator of Geology in the newly-created Department of Geology of the National Museum at Washington. After Dr. Hawes's

death in 1883, Mr. Yeates remained in charge of the mineral collections, as Assistant Curator and Acting Curator, until May, 1893, when he resigned to assume the position of State Geologist of Georgia. From 1884 to 1893 he was also Professor of Mineralogy, and from 1890 to 1893 of Geology also, in the Corcoran Scientific School of what was then Columbian (now George Washington) University, at Washington, D. C.

The personal publications of Prof. Yeates, as State Geologist of Georgia, were limited to a report on the gold-deposits of Lumpkin county (270 pp.) and five administrative reports, which were small pamphlets of from 9 to 45 pp. each. But under his administration a series of valuable preliminary reports was issued, covering the subjects of building-stone, manganese, phosphates, ochres, coal, gold, and other economic deposits, as well as the water-power and underground waters of the State.

His activity was, on the whole, that of an administrative officer rather than an original investigator. He was, however, an enthusiastic collector of minerals and thoroughly imbued with the "museum idea," a quality first developed during his period of service in Washington, and subsequently matured in connection with the Geological Survey of Georgia. Indeed, his taste and judgment in the selection of specimens and their installation for exhibition was perhaps his strongest characteristic; and the exhibits illustrating the resources of Georgia, made under his direction at Buffalo, St. Louis, and other great expositions of recent years, were in these respects not excelled, and rarely equaled, by those of any other State. The present State Geological Museum in Atlanta is wholly of his conception and execution, and a worthy monument of his genius in this line.

Prof. Yeates became a member of this Institute in 1895. He died at his home in Atlanta, Ga., Feb. 18, 1908.



## New York Tunnel Extension of the Pennsylvania Railroad System.\*

BY WILLIAM COUPER, NEW YORK, N. Y., ACTING SECRETARY OF THE BOARD OF ENGINEERS.

THE completion of the excavation of the tunnels through Bergen Hill for the extension of the Pennsylvania Railroad into New York City, together with the fact that the excavation for the rest of the tunnel-line has been practically completed for some time past, arouses sufficient interest to justify a description of the engineering- and contracting-work, and the organization by which it has been accomplished. The finishing of the excavation is a long step towards the completion of the entire tunnel-project.

It will be interesting to the members of the Institute, who last spring were taken through a great part of this work, to know that by the excavation now completed it is possible to walk by tunnel from a point near Sunnyside yard, Long Island, east of the 34th Street ferry, to the central passenger station site in the City of New York, and thence by tunnel to the Hackensack meadows, and by an embankment constructed across these meadows to Newark, N. J.

This New York tunnel extension is being constructed as a part of the Pennsylvania Railroad system by the Pennsylvania Tunnel & Terminal R. R. Co., a corporation of the States of New Jersey and New York.

It extends from a point near Newark, N. J., to the Sunnyside yard, Long Island, as indicated on the accompanying plan.

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\* [SECRETARY'S NOTE.—This description, prepared at my request, and by permission of the P. T. & T. R. R. Co., covers the whole work, a part of which, visited by the Institute in February, 1908, was described in the *Bi-Monthly Bulletin*, No. 20, March, 1908, pp. 275 to 288, and *Trans.*, xxxviii., pp. 360 to 397. The complete schedule of organization here given has been approved as correct by the management, which has also kindly furnished the accompanying map, engraved expressly to accompany this statement.—R. W. R.]

#### ENGINEERING ORGANIZATION.

The organization for constructing this extension is as follows:

1. The Vice-President of the company has general charge of all work involved in the execution of the project.

2. The Board of Engineers appointed by the management in 1902, to examine into the tunnel-project of the Pennsylvania R. R. Co. for the extension of its lines to a central passenger station in New York, and thence to Long Island, connecting with the Long Island Railroad; to pass upon the practicability of the undertaking; to determine upon the best plans for carrying it out; to make a careful estimate of its cost, and, if the work was undertaken, to exercise a general supervision over its construction.

The Board holds regular meetings to receive progress-reports from the Chief Engineers in direct charge of construction, and consider questions relating to the plans and details of the work submitted by its members or referred to it by the management. It then reports its conclusions to the management for approval before the work is undertaken.

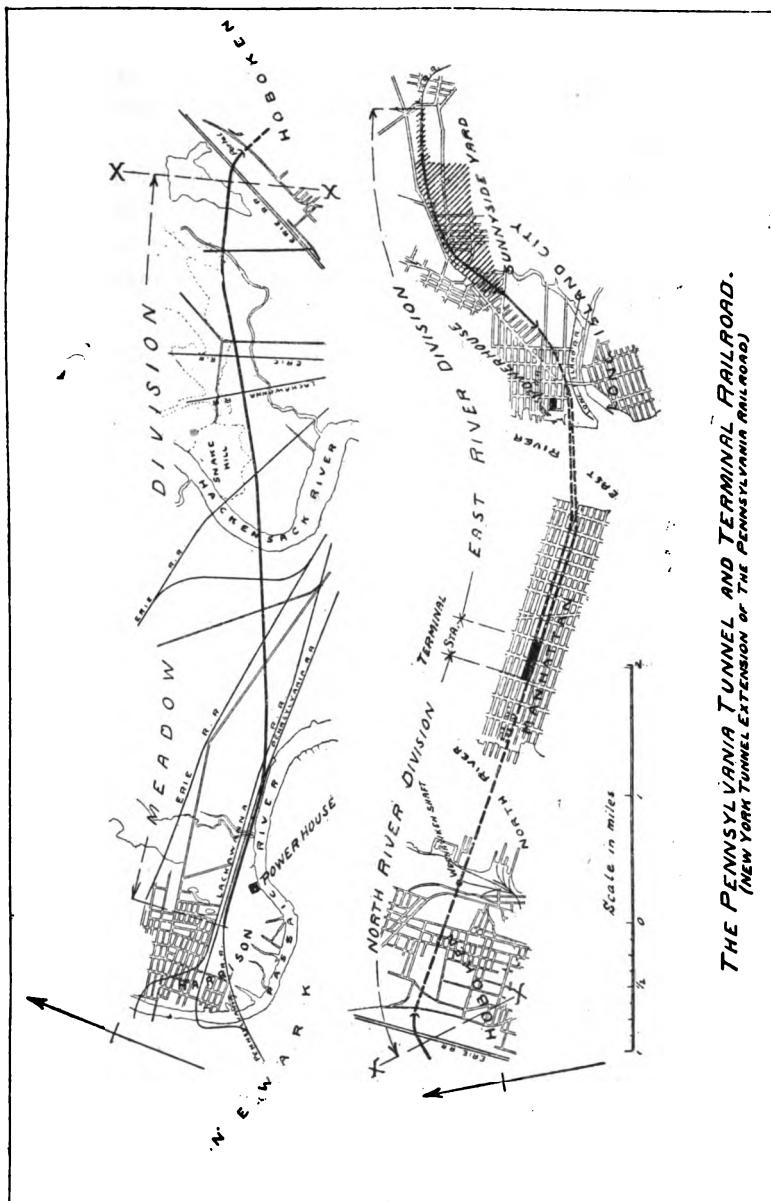
3. Chief Engineers in charge of the construction of the various Divisions. The Chief Engineers exercise full authority in the organization of the working-forces, and in the general conduct and management of the work of construction on their respective Divisions, in accordance with the plans for such work approved by the Board of Engineers and the management.

4. Architects were employed to design the Terminal Station building and superintend its erection, and structural engineers to design and erect steel structures and facilities and carry on the work under the direction of a Chief Engineer of the Terminal Company.

#### SUBDIVISION OF THE WORK.

For the purpose of actual construction, the line is divided into four parts: the Meadow Division, the North River Division, the Terminal Station, and the East River Division.

*The Meadow Division* consists of a double-track railroad, extending from a point near Newark, N. J., where it connects with the tracks of the Pennsylvania Railroad, across the Hackensack meadows to the west side of Bergen Hill, a distance



THE PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD.  
(NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD)

of 5.79 miles. The construction is principally embankment and bridge-work, including bridges across the Pennsylvania, Erie and Lackawanna Railroads and the Hackensack river.

*The North River Division* commences at the west side of Bergen Hill and passes through the hill in two single-track rock-tunnels to a large permanent shaft at Weehawken, near the west shore of the North river. It then passes under the river through two cast-iron, concrete-lined, single-track tunnels, with outside diameters of 23 ft., to a point under 32d St., near 11th Ave., in New York City, and thence through two single-track tunnels of varying cross-section, partly constructed in cut-and-cover, to the west side of the site of the Terminal Station near 9th Ave. The work includes the western retaining-wall at that place. The aggregate length of the line in this Division is 2.54 miles.

*The Terminal Station and Approaches* extend from a point near 9th Ave. to a point at the east side of 7th Ave. This part includes the construction of the Terminal Station building, service-buildings, subways, bridges, and other work connected therewith. The two electric power-houses, one already constructed at Long Island City and the other to be built at Harrison, N. J., are under the supervision of the Chief Engineer of Electric Traction and Terminal Station Construction.

The passenger-station building is to be 774 ft. long, 433 ft. wide, with an average height above the street of 69 ft. and a maximum of 153 ft. The main waiting-room is to be 277 ft. long, 103 ft. wide, and 150 ft. high. The Concourse will be 340 ft. long and 210 ft. wide. The level of the track-system below the street varies from 39 ft. to 58 ft., and access to the street is gained by means of elevators or stairways.

There will be 21 standing-tracks at the station, and within the station-area there will be a total of about 16 miles of track.

*The East River Division* commences at the eastern end of the site of the Terminal Station near 7th Ave. and passes through tunnels, partly three-track and partly two-track, under 32d and 33d St. The line then passes under the East river through four single-track, cast-iron, concrete-lined tunnels, with outside diameters of 23 ft., to a point near East Ave., Long Island City, and extends thence through tunnels and open cuts to Sunnyside

yard. This yard and a number of bridges crossing streets are included in this Division. The excavation for the Terminal Station and the retaining-walls around it, except the western one, were executed under this Division. The total length of the Division is 4.50 miles.

The total length of the entire line is 13.40 miles.

#### PERSONNEL OF THE MANAGEMENT.

##### *Directors.*

James McCrea, President, P. R. R. Co.  
 John P. Green, 1st Vice-President, P. R. R. Co.  
 Charles E. Pugh, 2d Vice-President, P. R. R. Co.  
 Samuel Rea, 3d Vice-President, P. R. R. Co.  
 Henry Tatnall, 5th Vice-President and Treasurer, P. R. R. Co.  
 Percival Roberts, Jr., Director, P. R. R. Co.  
 Thomas DeWitt Cuyler, Director, P. R. R. Co.  
 Clement A. Griscom, Director, P. R. R. Co.  
 John D. Crimmins, New York City.  
 F. L. Sheppard, General Superintendent, New Jersey Division, P. R. R. Co.

##### *Officers.*

James McCrea (President, P. R. R. Co.), President.  
 Samuel Rea (3d Vice-President, P. R. R. Co.), Vice-President.  
 A. J. County (Assistant to 3d Vice-President, P. R. R. Co.), Assistant to President.  
 Lewis Neilson (Secretary, P. R. R. Co.), Secretary.  
 Robert H. Groff (Assistant Secretary, P. R. R. Co.), Assistant Secretary.  
 Kane S. Green (Assistant Secretary, P. R. R. Co.), Assistant Secretary.  
 J. W. Marshall (Assistant to Secretary, P. R. R. Co.), Assistant Secretary.  
 Henry Tatnall (Treasurer, P. R. R. Co.), Treasurer.  
 Taber Ashton (Assistant to Treasurer, P. R. R. Co.), Assistant Treasurer.  
 W. W. Atterbury (General Manager, P. R. R. Co.), General Manager.  
 C. S. Krick, Superintendent.

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PERSONNEL OF THE ENGINEERING ORGANIZATION.

Samuel Rea, Vice-President.

*Board of Engineers.\**

Brig.-Gen. Charles W. Raymond, U. S. Army, Retired (Late Colonel Corps of Engineers), Chairman.

Charles M. Jacobs, Chief Engineer, North River Division.

Alfred Noble, Chief Engineer, East River Division.

George Gibbs, Chief Engineer of Electric Traction and Terminal Station Construction.

S. Johannesson, Engineer Assistant to the Chairman.

William Couper, Acting Secretary of the Board.

*Meadow Division.*

Alexander C. Shand (Chief Engineer, P. R. R. Co.), Chief Engineer.

E. B. Temple (Assistant Chief Engineer, P. R. R. Co.), Assistant Chief Engineer.

J. F. Murray (Assistant to Chief Engineer, P. R. R. Co.), Assistant to Chief Engineer.

Wm. C. Bowles, Engineer of Construction.

*North River Division.*

Charles M. Jacobs, Chief Engineer.

James Forgie, Chief Assistant Engineer.

B. H. M. Hewett, General Resident Engineer, River Tunnels.

W. Lowe Brown, Resident Engineer, River Tunnels.

F. Lavis, Resident Engineer, Bergen Hill Tunnels.

B. F. Cresson, Jr., Resident Engineer, Terminal Station West.

*Terminal Station.*

George Gibbs, Chief Engineer of Electric Traction and Terminal Station Construction.

E. R. Hill, Assistant to Chief Engineer.

Westinghouse, Church, Kerr & Co., Engineers.

McKim, Mead & White, Architects.

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\* Mr. Gustav Lindenthal, late Bridge Commissioner, New York City, and Mr. W. H. Brown, late Chief Engineer, P. R. R. Co., served as members of the Board until their respective resignations, the former on Dec. 15, 1903, and the latter on Mar. 1, 1906.

*East River Division.*

Alfred Noble, Chief Engineer.

Charles L. Harrison, Principal Assistant Engineer.

James H. Brace, Resident Engineer.

S. H. Woodard, Resident Engineer.

George Leighton, Resident Engineer.

Francis Mason, Resident Engineer.

George C. Clarke, Resident Engineer.

Lewis H. Barker, Resident Engineer.

**SPECIAL COMMITTEES.**

In addition to and acting in co-operation with the foregoing Engineering staff, special Committees and sub-Committees were organized to consider special branches and features connected with the project, so that the experience of the Pennsylvania R. R. Co.'s organization might be utilized in the work. The following committees may be mentioned as illustrations:

1. New York Terminal Passenger Station, Joseph T. Richards (Chief Engineer Maintenance of Way, P. R. R. Co.), Chairman.
2. New York Terminal Passenger Yard, Joseph T. Richards (Chief Engineer Maintenance of Way, P. R. R. Co.), Chairman.
3. Terminal Operation, Joseph T. Richards (Chief Engineer Maintenance of Way, P. R. R. Co.), Chairman.
4. Special Mechanical and Electrical Features, Theodore N. Ely (Chief of Motive Power, P. R. R. Co.), Chairman.

**CONTRACTORS.**

The following is a list of the principal contractors:

*Meadow Division.*

Substructure: McMullen & McDermott; The Drake & Stratton Co.

Embankments: H. S. Kerbaugh, Inc.; Henry Steers, Inc.

*North River Division.*

Bergen Hill Tunnels: William Bradley.

Weehawken Shaft: The United Engineering & Contracting Co.

River Tunnels: The O'Rourke Engineering Construction Co.

Manhattan Shaft: The United Engineering & Contracting Co.

Terminal Station West: New York Contracting Co., Pennsylvania Terminal.

*Terminal Station.*

Excavation: New York Contracting Co., Pennsylvania Terminal.

Building: George A. Fuller Co., Contractor, and other Contractors and sub-Contractors.

Steel: Milliken Brothers, Inc.; American Bridge Co.

*East River Division.*

Cross-town Tunnels: The United Engineering & Contracting Co.

River Tunnels: S. Pearson & Son, Inc.

Long Island Approaches: Naughton Co. and Arthur McMullen.

Terminal Yard: The Degnon Realty & Terminal Improvement Co.

## The Carbon-Iron Diagram.

BY HENRY M. HOWE, NEW YORK, N. Y.\*

(New York Meeting, February, 1908.)

### PART I.

§ 1. *Introduction.* After giving certain definitions, this paper gives the reasons which led to Roozeboom's form of the diagram of the freezing-point curves and general equilibrium of the iron-carbon compounds, steel and cast-iron; and then those which led to replacing it with the present or double diagram, in which graphite is at all temperatures held to be the more stable and cementite the less stable (metastable) form of carbon. Next in § 10 the evidence supporting this greater stability of graphite is examined, then in § 17 that which seems to oppose it, and in § 22 a summary of the evidence is presented.

The second part of the paper considers the topography of the graphite-iron diagram, rejecting summarily the solubility-lines based on the data of Charpy and Grenet and of Mannesmann, on the ground that the data even on their face do not really point toward these lines, and that they are wholly incompetent to determine any solubility-lines whatsoever, because they report together with the dissolved carbon also an indeterminate quantity of cement-carbon, and because even such carbon as is actually dissolved, only in part represents the solubility of graphite, and in another and indeterminate part represents the solubility of cementite, or at least of carbon in presence of cementite as distinguished from graphite.

It might be thought that graphite is but slightly soluble in iron, because of the absence of any suggestions of eutectoid graphite, corresponding to the eutectoid cementite of pearlite in very many cases in which the cast-iron seems to consist of ferrite and massive graphite only, and because of the micrographs of Goerens and Gutowsky. In these the primary austenite of cast-iron quenched but little below the eutectic freezing-

\* Professor of Metallurgy in Columbia University in the City of New York.

range, though richly pierced with cementite needles where it adjoins the cementite-austenite eutectic, is free from graphite where it adjoins the graphite-austenite eutectic, indicating that there has been no marked decrease in the solubility of graphite during cooling, and thus suggesting that that solubility itself is very slight.

But on the other hand the very readiness with which the graphite of iron which initially contains little or no cementite changes into cementite on heating and again cooling, certainly indicates that graphite dissolves rapidly, and suggests that its solubility is considerable, because on our present theory that graphite is more stable than cementite, this change can occur only through the dissolving of the graphite and its re-precipitation as cementite. Further evidence is needed to decide this question.

An appendix gives a diagram on Prof. Sauveur's plan, representing the relation between the quantity of the different varieties of cementite and the total carbon-content.

§ 2. *Subdivision of the constituents of iron and steel.* The graphite in cast-iron may come into existence at several different stages in the history of the specimen. Kish comes into existence during the early part of the freezing, before the eutectic freezing-point has been reached; some of the graphite is born in the freezing of the eutectic; still another part, such as the temper-graphite of malleable castings, is born at lower temperatures. So with different parts of the cementite and of the ferrite both of steel and of cast-iron. In trying to convey my ideas to others, and in trying to understand theirs, I have been struck with the need of some simple terms which would indicate clearly the genesis of each of these different constituents. Here are certain of these terms.

§ 3. *Definitions. Austenite.* The normal constituent of region 4 of Fig. 1, a solid solution of carbon or of an iron carbide in gamma allotropic iron, is usually spoken of as "gamma iron" or "mixed crystals." When cooled below region 4 it of course tends to split up into ferrite and cementite, but when it contains much carbon, say 1.5 per cent., this decomposition may be restrained in large part by very rapid cooling, so that the solid solution is preserved in the cold but little decomposed. When thus preserved it is called "austenite." It seems to

some, myself included, that our terminology and our explanations would be greatly simplified by extending the meaning of austenite so as to include, not only this, the least decomposed cold form of this solid solution, but also the undecomposed solid solution itself as it exists in region 4 and elsewhere. Therefore I propose the following definition, which I follow in the present paper.

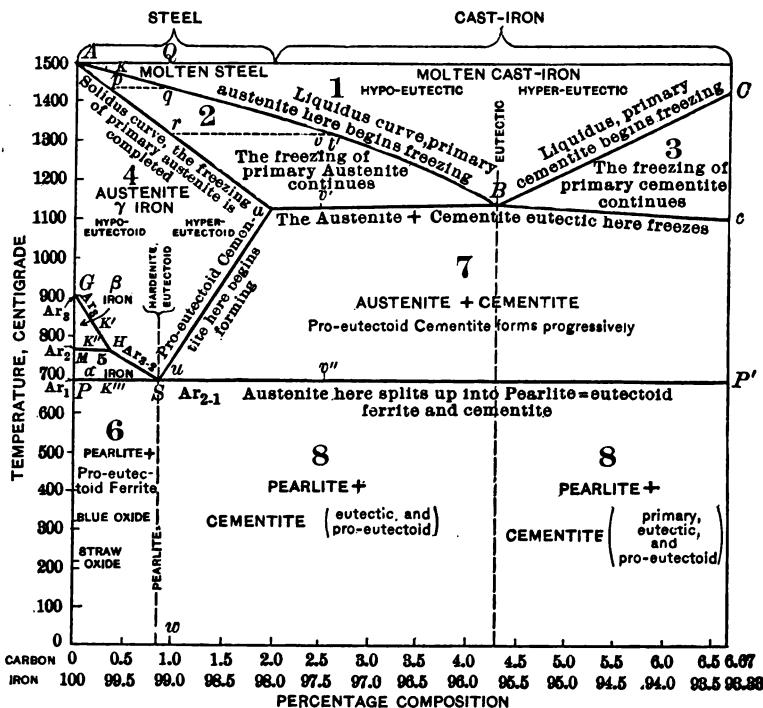


FIG. 1.—ROBERTS-AUSTEN OR CARBON-IRON DIAGRAM. THE CEMENTITE-AUSTENITE OR METASTABLE FORM.

(1) “Austenite,” (A) *Generically*, the solid solution of iron carbide in iron, stable, for instance, above the transformation-range  $A_1$  to  $A_3$ . (B) *Specifically*, this same solid solution as preserved in the cold more or less decomposed, for instance by quenching steel containing more than 1.5 per cent. of carbon from above  $1,100^{\circ}$  C. in ice-water. When the structure of such steel is developed by polishing on parchment moistened with licorice solution or ammonium nitrate after reheating to  $200^{\circ}$ , or by etching with hydrochloric acid in an electric current, the austenite remains white, while the zig-zag martensite with which

it is often associated becomes brown. (This paragraph follows approximately the definition of the committee of the Iron and Steel Institute.)<sup>1</sup>

(2) *Primary austenite*, that which separates from the molten metal in cooling through region 2 of Fig. 1.

(3) *Primary cementite*, that which separates from the molten metal in cooling through region 3.

(4) *Eutectic austenite*, that which forms on crossing the boundary  $aBc$  in cooling from region 2 or 3 into region 7, and forms part of the eutectic.

(5) *Eutectic cementite*, that which forms on crossing the boundary  $aBc$  in cooling from region 2 or 3 into region 7, and forms part of the eutectic.

(6) *Pro-eutectoid ferrite*, that which forms from the austenite in cooling through region 5. It is the same as "excess ferrite."

(7) *Pro-eutectoid cementite*, that which forms in the austenite in cooling through region 7, and therefore immediately precedes the eutectoid cementite, *i.e.*, that of the pearlite formed on cooling past  $Ar_1$ . To the objection that the primary and the eutectic cementite also precede the eutectoid and hence might be called pro-eutectoid, it is a sufficient answer that "ante-bellum" days are understood to include only these shortly before the war in question, and not to include those of Homer, Adam, and the azoic period. There is no reason why it should not be conventionally agreed that "pro-eutectoid" refers only to the stage which precedes the eutectoid immediately.

(8) *Eutectoid ferrite*, that which forms in crossing the line  $PSP'$ , or  $Ar_1$ , in cooling from region 5 or region 7 into region 6 or 8. So with *eutectoid cementite*.

(9) *Primaustenoid*, the network, spines, and other masses rich in ferrite and therefore poor in carbon which, in hypo-eutectoid steel, persist as undiffused relics of the primary austenite formed in cooling through region 2. They are the white masses such as *A*, shown in Fig. 2. As the name suggests, they have the general shape of the austenite, from the decomposition of which in region 5 they result. So long as they persist the heat-treatment or the mechanical work which the metal has undergone cannot be considered as complete, though it may be sufficient for many purposes.

<sup>1</sup> *Journal of the Iron and Steel Institute*, vol. Ixi. (1902, No. 1), p. 94.

(10) *Primaustenal*, adj., of or relating to primaustenoid.

Many of these subdivisions must have occurred to other writers; I lay no claim to originality in proposing them. Indeed, some of the names themselves, Nos. 2 to 5, are already in use, either in their present form or in some like form. The only ones which seem to me distinctly new are those numbered 6 to 10 inclusive. My own personal experience as teacher, investigator, writer, and manufacturer convinces me that these

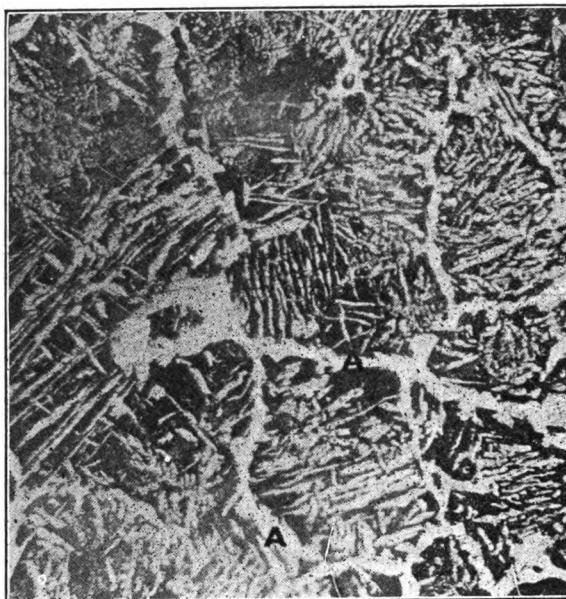


FIG. 2.—PRIMAUSTENOID NETWORK IN UNANNEALED STEEL. A = THE PRIMAUSTENOID. C = 0.42, Si = 0.47, Mn = 0.58.

subdivisions are useful in discussing and explaining the phenomena.

The pro-eutectoid ferrite is clearly that which Prof. Sauveur has called "structurally free ferrite." I have hitherto called it "excess" ferrite. The primary, eutectic, and pro-eutectoid cementite jointly form what Prof. Sauveur has called "structurally free" cementite, and I have hitherto called "excess cementite." Indeed, it is the need of subdividing this excess cementite and assigning a specific name, "pro-eutectoid," to that which separates in cooling through region 7, that has led me to propose the name "pro-eutectoid ferrite" instead of

“excess ferrite.” The former has the merit not only of matching the corresponding cementite, but of indicating the genesis.

The eutectoid ferrite and cementite are clearly those which result from the splitting up of the hardenite and are habitually interstratified as pearlite.

On the same general plan, if the austenite-graphite diagram, Fig. 4, instead of the austenite-cementite diagram is followed, then the graphite which forms in cooling through region III is primary graphite; that which forms on cooling past the line  $aBc$  is eutectic graphite, etc. Thus “kish” is primary graphite; most of the graphite seen in the fracture of gray cast-iron is probably eutectic; while as to the temper-graphite of malleable cast-iron and of black file-steel something will be said later on in this paper.

§ 4. *Roozeboom on the carbon-iron diagram.* The interpretation of the left-hand part of the diagram, Fig. 1, is relatively simple, because here the only very permanent phases are ferrite, cementite, and austenite. Moreover, there is nothing to suggest that at any time more than two of these are in equilibrium, except at the moment when, in passing across the boundary-line which separates one region from another, one system is changing into another. Thus in region 4 there is only austenite; in region 5 only austenite and ferrite; in region 6 only ferrite and cementite. With two components, iron and carbon, two phases may be in monovariant equilibrium with each other, *i. e.*, they may form a system which can, without passing out of equilibrium, survive at least a limited rise or fall of temperature; in short, a system which is in equilibrium not simply at some single precise temperature, as is the case with nonvariant systems, but through a range of temperature, though that range may be wide or narrow.

But when the percentage of carbon is so high that graphite forms, a difficulty arises. We still have only two components, iron and carbon, but we have four phases, austenite, graphite, cementite, and ferrite, and in many cases, indeed in most cast-irons, we have three of these phases present simultaneously, austenite, cementite, and graphite above the line  $PSP'$  or  $A_1$ , and ferrite, cementite, and graphite below the line. But the phase-rule declares that, in a two-component system, not more than two phases can be in monovariant equilibrium.

This conflict with the phase-rule was to be explained away

by assuming that what we have to do with here are not really three-phase systems at all, but two different sets of two-phase systems, overlapping through lag, one set with cementite and the other with graphite as a characteristic phase. Two courses were open. Both sets might be equally stable, in which case the stability of each would necessarily be confined to some special range of temperature, because two sets could not be stable simultaneously; or one set might at all temperatures be of less stability than the other, *i. e.*, metastable, and always tending to change over into the other or stable set.

Roozeboom very naturally chose the former theory, because each of these sets certainly does seem at first sight to be stable. Witness the phenomena of two important and familiar processes, first that of cementing steel, and, second, that of "malleabilizing" cast-iron, *i. e.*, of changing white and hence cementitiferous cast-iron into gray and hence graphitiferous cast-iron by long heating. In the cementation process, starting with pure iron and the foreign-graphite which can be used for carburizing it, the two-phase system (?) foreign-graphite + austenite changes into the other two-phase system cementite + austenite, as is implied by the fact that most of the carbon in the cemented steel after cooling usually exists as cementite. Hence, indeed, came the name "cement carbon," and hence in turn the very name "cementite." Here then the system cementite + austenite produces the impression of being not only stable, but more stable than the system foreign-graphite + austenite, because here the latter system actually changes into the former. On the other hand, in the equally familiar process of making malleable cast-iron by holding white cast-iron in region 7, the system cementite + austenite very certainly does change over into the other system graphite + austenite. Here then the latter system is evidently not only stable but more stable than the former. Hence the natural inference that each system in fact is more stable than the other in some certain zone of temperature, and that on crossing the boundary which separates those zones the constitution should change from the system stable in the zone left to the system stable in the zone entered.

What were these two zones? The habitual formation of graphite in the slow solidification of cast-iron certainly suggested that at the freezing-point graphite was a stable phase, and hence that the region in which the system graphite + austenite

is stable includes the freezing-point, and hence in turn that the graphite + austenite region lies above the cementite + austenite region. Roberts-Austen had noticed a retardation of the cooling of cast-iron between the freezing-point  $aBc$  and  $Ar$ . This retardation ought to represent some reaction or transformation within the solid metal. Putting two and two together, what more natural than to suppose that this represented a change from the system graphite + austenite into the system cementite + austenite by the reaction (1)  $Gr. + 3Fe = Fe_3C$ ? The phase-rule implies that the boundary-line between two monovariant systems must, in equilibrium, be strictly horizontal, *i. e.*, that the temperature at which one system changes over into the other is a fixed one independent of the proportion between the two phases in either system, for the obvious reason that equilibrium is evidently a thing wholly independent of the relative quantities of the different phases present. This, of course, refers to the temperature at which the transformation is due. That at which it actually occurs may be shifted by lag.

Putting these various things together, we naturally come to the Roozeboom diagram represented in a general way by Fig. 3. The underscored-V group of freezing-point lines,  $ABC$ ,  $aBc$ , represented the formation of austenite and graphite from the molten cast-iron; below this line, in region 7A of Fig. 3, the graphite and austenite which had formed in freezing were stable; the retardation observed by Roberts-Austen represented the change from graphite to cementite (1)  $Gr. + 3Fe = Fe_3C$ ; and in region 7B austenite and this cementite were stable. The graphite habitually found in most cast-irons was simply that which had not had time to change over into cementite, and it was therefore present by lag, and was clearly out of equilibrium. The facts so strongly in contrast that in the cementation process it is cementite that forms from the union of the iron under treatment and the cementing material, even if this is pure graphite, (1)  $Gr. + 3Fe = Fe_3C$ , whereas in the malleabilizing process graphite and austenite result from the decomposition of the cementite originally present (2)  $Fe_3C = 3Fe + Gr.$ , are explained by supposing that the cementation process takes place below the line  $ER$ , and the malleabilizing process above that line.

This was a very pretty fabric, and at first sight it seemed to reconcile many conflicting facts. Unfortunately, other evidence

soon appeared with which it could not well be reconciled. This Dr. Benedicks has massed together in a very convincing form, adding a wealth of important new observations, which strengthen the present theory immeasurably.<sup>2</sup> Let us now consider some of this evidence, and later let us consider an explanation of the retardation at 1,050°. See § 55, p. 521.

§ 5. *The facts which oppose Roozeboom's theory.* (A) *The reaction (1) could not cause a retardation.* A retardation in cooling must of course be caused by some reaction or change which

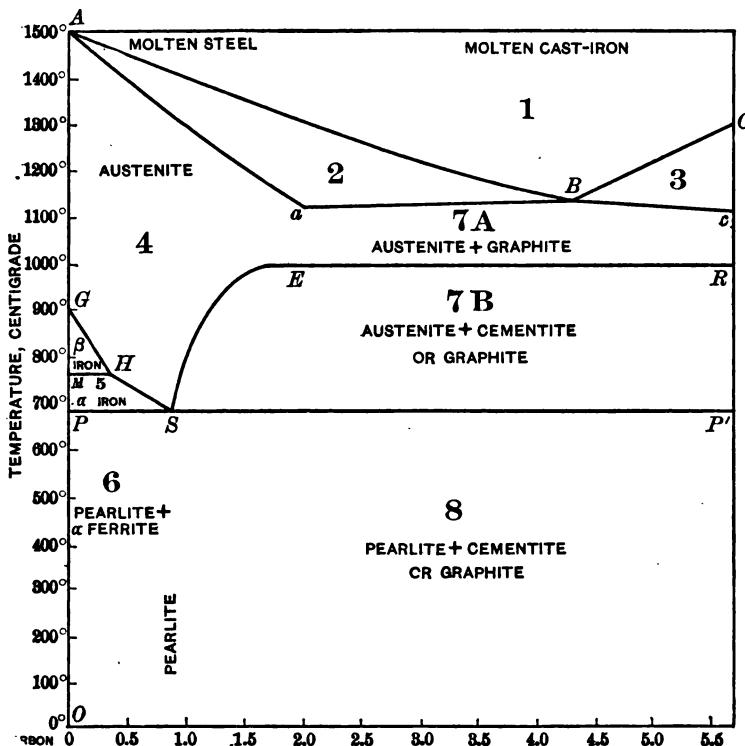


FIG. 3.—GENERAL FEATURES OF ROOZEBOOM'S DIAGRAM OF THE FREEZING-POINT AND EQUILIBRIUM OF THE IRON-CARBON COMPOUNDS.

evolves heat, because it necessarily implies that from some source heat is supplied to take the place of part of that which is escaping from the cooling mass. In short, whatever causes this retardation must needs be an exothermic reaction. But the results of Troost and Hautefeuille, later confirmed by E. D. Campbell, show that this reaction, if it took place, would be endothermic. This may further be inferred from Wüst's discovery that the retardation at the eutectic freezing-point, though

<sup>2</sup> *Metallurgie*, vol. iii., No. 12, p. 393 (June 22, 1906).

it bore no constant relation to the carbon-content between the limits of 3.66 and 4.66 per cent., in general increased with the proportion of graphite which formed.<sup>3</sup> His results are rearranged in Table II. so as to show this. It is true that the re-

TABLE II.—*The Eutectic Retardation Increases with the Graphite. From Wüst's Data.*

|  |      |      |      |      |      |      |      |      |
|--|------|------|------|------|------|------|------|------|
| Total carbon-content, per cent....                         | 3.82 | 3.66 | 4.04 | 3.79 | 3.94 | 3.76 | 4.04 | 4.66 |
| Graphite-content, per cent.....                            | 0.02 | 0.51 | 1.75 | 2.24 | 2.28 | 2.33 | 2.49 | 3.22 |
| Length of arrest, seconds, at eutectic freezing-point..... | 70   | 120  | 210  | 350  | 290  | 310  | 320  | 270  |

sults of Osmond and Werth indicated that the reaction is exothermic; but their experiments were less conclusive than those of these other observers, and indeed M. Osmond himself accepts the endothermancy of this reaction.

§ 6. (B) *The cementation and malleablizing processes do not obey Roozeboom's theory.* Instead of its being true, as this theory implies, that exposure to region 7A of Roozeboom's diagram always leads to the formation of graphite, and exposure to region 7B always to the formation of cementite, the cementation process normally gives rise to cementite even in region 7A and the malleablizing process of changing cementite into graphite is by no means confined to region 7A, but goes on at much lower temperatures. Thus the normal annealing-temperature in some of the best American malleablizing practice is only 730° (say 1,350° F.), and the process can be carried out even at 677° (say 1,250° F.). Indeed, Charpy and Grenet raised the graphite-content of cast-iron containing 2.10 per cent. of silicon, from 0.10 to 2.83 per cent. by heating it for 6 hr. at 650°,<sup>4</sup> and out of the 2.95 of carbon which Saniter<sup>5</sup> made pure iron absorb by heating in contact with charcoal at about 900°, 0.53 per cent was graphitic.

§ 7. (C) *The change of combined carbon into graphite takes place at all temperatures between the freezing-point and 650°*, as has now been shown clearly by the concordant and extended experiments of Charpy and Grenet,<sup>4</sup> Heyn and Bauer,<sup>6</sup> and Goerens

<sup>3</sup> *Metallurgie*, vol. iii., No. 22, p. 757 (Nov. 22, 1906). (I do not know that Prof. Wüst actually draws this inference.—H. M. H.)

<sup>4</sup> *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, vol. cii., p. 401 (1<sup>re</sup> semestre, 1902).

<sup>5</sup> *Journal of the Iron and Steel Institute*, vol. lii. (1897, No. II.), p. 122.

<sup>6</sup> *Stahl und Eisen*, vol. xxvii., No. 44, p. 1568 (Oct. 30, 1907).

and Gutowsky,<sup>7</sup> cases 1 to 5, 17 and 18, and 28 of Table I., p. 526, and by other experiments mentioned in § 16.

In cases 1 to 5, when like specimens of cast-iron were held at different temperatures, QT, all the way between 650° and 1,170° and were then quenched so as to retain the carbon in the state there reached, this carbon, which was initially all or nearly all combined, and in large part cementite, was found to have changed in part into graphite at all of these temperatures. This change was in general the more complete the lower the QT, but even at 1,100° and 1,170° it went far.

In cases 17, 18, and 28, when cast-iron was quenched after cooling slowly from above the freezing-point to a series of lower temperatures, QT, the combined carbon changed into graphite progressively as QT was progressively lowered. This graphitization took place all the way from the freezing-point to below 900° in case 17, to below 800° in case 18, and to below 750° in case 28.<sup>8</sup> This proof that graphitization is more complete at lower temperatures, 900° and 800°, than at those above 1,000° and 1,100°, directly disproves this theory of Roozeboom's that graphite is stable only above and cementite only below a certain critical temperature near 1,000°. The fact that graphitization was indeed more rapid just below the freezing-point than at lower temperatures is of course readily explained by the greater molecular freedom at the higher temperatures. Thus most of the change from combined carbon to graphite took place in the first 40° below the end of the freezing.

<sup>7</sup> *Metallurgie*, vol. v., No. 5, p. 145 (Mar. 8, 1908).

<sup>8</sup> The persistence of graphitization at temperatures below 900° and even 800° is shown more clearly by the arrangement of Heyn and Bauer's results in Table I., which reports the combined carbon left ungraphitized, than in the arrangement shown by the investigators themselves, who report the graphite itself. Graphitization, a change from the combined or cementite and the dissolved carbon into graphite, is limited and regulated not so much by the quantity of graphite present, as by the quantity of carbon which remains dissolved and combined. The graphite actually formed is simply the difference between the total carbon present, which in these cases depends on the conditions above the melting-point and also on how much carbon has been burnt away, and the carbon which remains dissolved and combined. The progress of the shrinkage of volume of a rubber hot-water bag which I am compressing is to be learnt from the volume of water which remains in the bag, from moment to moment, and not from that which is outside the bag, because this includes not only what I have ejected by my compression but also that which ran over while I was filling the bag.

In both the cast-irons which Heyn and Bauer studied, one with between 2.90 and 4.27 per cent. of silicon, and another with between 1.20 and 1.72 per cent. of silicon, but little graphite formed during freezing proper. Both cast-irons froze as white iron, but immediately after freezing was complete graphite formed rapidly. (See § 12 and Table III.)

§ 8. (D) *Microscopic evidence.* If, in the cast-iron which contains both graphite and cementite, that cementite had been formed by the reaction between the graphite, both primary and eutectic, and the austenite present (1),  $\text{Gr.} + 3\text{Fe} = \text{Fe}_3\text{C}$ , as Roozeboom's theory implies, and if the graphite present were simply that which had not yet had time thus to become converted into cementite, in short, was simply the residual unconverted core, then manifestly this unconverted core should be surrounded by the cementite resulting from the conversion of the graphite which originally incased that core. But this is not the case.\* The graphite plates in such iron may be surrounded by ferrite or by pearlite, but not by cementite. Instead the islands of cementite are at a distance from this graphite. In short, the littoral region about the supposed residual islands of graphite instead of being the part richest in cementite is rather the part poorest in cementite, as if the reaction had been rather a precipitation of graphite out of cementite than a creation of cementite out of graphite, rather (2)  $\text{Fe}_3\text{C} = 3\text{Fe} + \text{Gr.}$  than (1)  $\text{Gr.} + 3\text{Fe} = \text{Fe}_3\text{C}$ . This is illustrated in Fig. 3A, in which the white islands, A, of the cementite-austenite eutectic are far separated from the black sheets of graphite.

§ 9. *The present or double diagram theory.* This theory completely rejects the idea of the zones 7A and 7B of the Roozeboom diagram, with graphite the more stable substance in the upper and cementite the more stable in the lower zone, and instead regards graphite as always and under all conditions the more stable and cementite the less stable of the two, or in other words the metastable form, so that cementite is always trying to change into graphite, just as the austenite and martensite of hardened steel are always trying to change into

\* Heyn, *Iron and Steel Magazine*, vol. x., No. 1, p. 50 (July, 1905). Also Benedict, *Metallurgie*, vol. iii., pp. 472-3 (No. 14, July 22, 1906), and micrograph 25 after p. 432 (No. 13, July 8, 1906).

ferrite and cementite. The theory gives us a double diagram, the cementite-austenite diagram which we have seen in Fig. 1, and roughly parallel with it the graphite-austenite diagram shown in Fig. 4, in which certain of the lines of the cementite-austenite diagram are reproduced to facilitate the explanation. This double diagram was, indeed, outlined in Roberts-Austen's<sup>10</sup> early diagram in 1899 at the suggestion of Le Chatelier.

According to this theory, when cast-iron freezes the whole

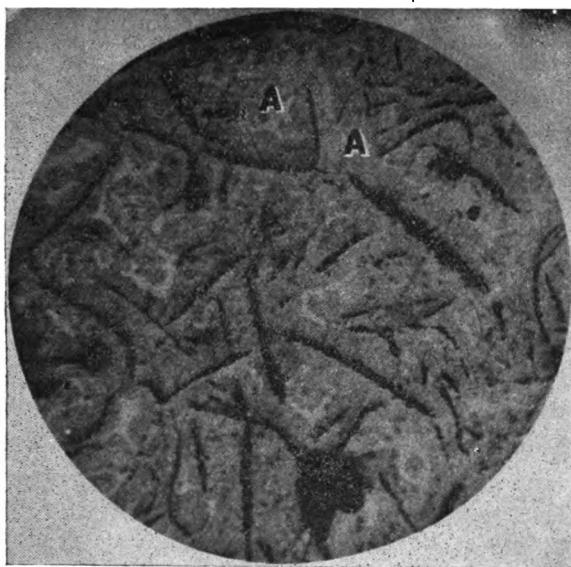


FIG. 3A.—NO. 3 FOUNDRY-IRON. PROFESSOR WM. CAMPBELL.

Silicon, 2 per cent.; sulphur, 0.05 per cent. 55 diameters. Vertical.

mass may (1) obey the austenite-cementite diagram; so that a cast-iron wholly free from graphite, *i. e.*, a typical white cast-iron results, consisting of ferrite and cementite only, metastable, *i. e.*, relatively unstable; or (2) the whole mass may obey the graphite-austenite diagram so that no cementite forms, and that the mass as a whole in cooling becomes a mixture of graphite and ferrite, as in ultra or typical gray cast-iron, perfectly stable; or (3), as is usually the case, certain molecules may follow one

<sup>10</sup> *Fifth Report to Alloys Research Committee*, read before Institution of Mechanical Engineers, Feb. 9, 1899, Fig. 10, Plate 4, *Proceedings of the Institution of Mechanical Engineers* (1899).

diagram and certain others may follow the other, so that the mass as a whole consists of two parts, theoretically distinct but in fact usually mixed up, one which has obeyed the cementite-austenite diagram, and hence when cold consists of a mixture of ferrite and cementite, and the other which has obeyed the graphite-austenite diagram, and hence when cold consists of a mixture of graphite and ferrite. Thus the cast-iron as a whole is a conglomerate of these two mixtures. This latter case is

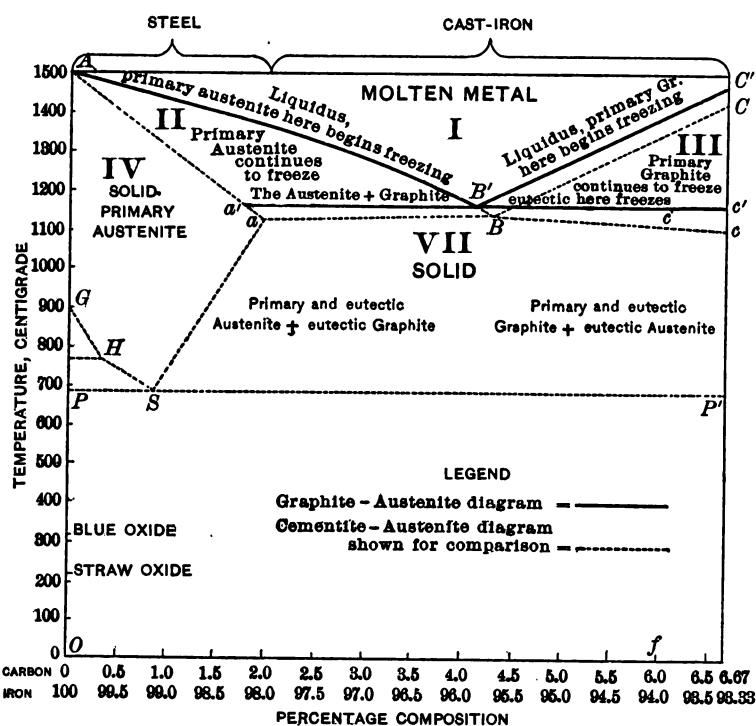


FIG. 4.—GRAPHITE-AUSTENITE OR STABLE CARBON-IRON DIAGRAM.

well exemplified by mottled cast-iron, with its patches of gray and patches of white.

Let us look briefly first (§ 10) at the facts which evidently support the present theory, that graphite is at all times and under all conditions the more stable and cementite the less stable, so that the presence of graphite in cast-iron is by right and not by lag, and that it is cementite that is present by

lag; let us next (§ 17) consider certain facts which at first seem to oppose this theory.

§ 10. *Evidence of the greater stability of graphite than of cementite.* This theory, of course, accords easily with the phenomena of the malleablizing process, the essence of which is that the mixture of cementite and ferrite, of which white cast-iron initially consists, changes slowly into a mixture of graphite and austenite when long held at a temperature of about 900° C. So when high-carbon steel is held for a long time at a high temperature it undergoes a like graphitization, and loses part of its hardening power.<sup>11</sup> (See K and L, § 16.)

Next come two important facts which argue strongly that graphite is more stable than cementite. These facts are (1) that it is rapid cooling that yields cementite and slow cooling that yields graphite; and (2) that the eutectic cementite, in and immediately after the act of freezing, *i. e.*, very soon after its formation, begins changing into graphite.

Of course it is but natural that the more time is given for reaching stable equilibrium the nearer should be the approach to that equilibrium; hence we naturally infer that graphite, the condition which is reached by slow cooling, is more stable than cementite, that reached by rapid cooling. Hence our first fact argues that graphite is the more stable of the two conditions.

The second fact, the change of the eutectic cementite into graphite, is further evidence that graphite is the more stable of the two, because whatever change occurs is naturally in the direction of the greater stability. Indeed, it is the usual order of things that the metastable form is the one most readily entered, and that this later changes over into the stable form.<sup>12</sup>

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<sup>11</sup> *The Treatment of Steel*, Wm. Metcalf, revised and reprinted by the Crucible Steel Co. of America, p. 88 (1902).

<sup>12</sup> Ostwald says, *Grundriss der Allgemeinen Chemie*, p. 312 (1899): "Wenn man, das metastabile Gebiet überschritten hat, und es entsteht eine neue Phase freiwillig, so macht sich das bemerkenswerte Gesetz geltend, dass die entstehende Form nicht die unter den vorhandenen Umständen beständige ist, sondern im Gegenteil die wenigst beständige, d. h. die in Bezug auf ihre Beständigkeit der sich umwandelnden Form zunächst liegende. Die Erscheinung ist außerordentlich verbreitet."

An interesting illustration of this law that the form most readily entered is not usually the most stable, has lately been reported by Dr. A. L. Day. We often think

§ 11. *Precedence of the metastable to the stable.* This order is readily understood if we liken it to what happens to a lot of well-loaded arrows which I throw pell-mell out of the window, so that they fall upon the soft asphalt sidewalk. No matter in what position any individual arrow is when it leaves my hand, it will strike and sink into the asphalt head-foremost, *i. e.*, in the vertical or metastable position, and will reach the horizontal or stable position later only when some favoring condition permits the change to occur. For instance, if the weather grows very hot and the asphalt softens, relaxing its frictional resistance, the arrows begin toppling over and approaching the horizontal or stable position, quite as when white cast-iron is highly heated in the malleablizing process the frictional resistance or molecular rigidity is so far relaxed that the metastable cementite is able to obey its natural impulse and topple over into the stable forms of graphite and austenite. Whatever change takes place is in the direction of greater stability. No arrow which has fallen flat will right itself and stand on end, nor should graphite change back into cementite.

In the case of the carbon-iron diagram this order is all the more easily understood if we accept the theory that the carbon in the molten iron exists dissolved as a solution not of elemental carbon, *i. e.*, graphite, but of cementite in the molten iron. The quick freezing does not give time for the change from the cementite to the graphitic state; slow freezing does.

§ 12. *The evidence detailed.* Of the two facts (1) that rapid cooling yields cementite and slow cooling graphite, and (2) that the eutectic cementite early begins changing into graphite, the first is a matter of such common observation that we need not here detail the abundant specific evidence on which it rests. The second is established by the very concordant results of Heyn and Bauer, of Goerens and Gutowsky, and of Osmond, condensed in Table III.

The fact that in No. 18 but very little graphite was present when the slow cooling was interrupted by quenching

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that the conditions which exist in rock-forming should give rise to the most stable forms, because here there is such ample time. But the particular form of magnesium silicate, enstatite, which is common in nature, Dr. Day finds is not the stable one. Enstatite and two others of the four forms of this silicate can be changed into the fourth, but this cannot be changed back into any of the others. Therefore this fourth is the stable form. *Fifth Year Book of the Carnegie Institution*, p. 178 (1906).

TABLE III.—*The Formation of Graphite Takes Place Chiefly Just Below the Freezing-Point of the Cementite-Austenite Eutectic.*

| Authority.                      | Composition of Iron.  |                  |                 |                | Percentage of Graphite. |       |       |       |       |       |       |      |      |      |      |      | Degrees below the Eutectic Freezing-Point, approximately. |       |      |      |      |      |
|---------------------------------|-----------------------|------------------|-----------------|----------------|-------------------------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|---|-------|------|------|------|------|
|                                 | Total C.<br>Per Cent. | Si.<br>Per Cent. | Fe<br>Per Cent. | Per<br>Cent.   |                         |       |       |       |       |       |       |      |      |      |      |      |   |       |      |      |      |      |
|                                 |                       |                  |                 |                | 20°                     | 5°    | 8°±   | 0°    | 11°   | 18°±  | 20°±  | 30°  | 41°  | 45°  | 48°± | 130° | 138°  | 198°± | 220° | 270° | 370° | 510° |
| 17 Heyn and Bauer. <sup>a</sup> | 3.05 to 3.33          | 1.20 to 1.72     | 0.22± to 0.29   | 0.09± to 0.06± | 0.33± to 0.36           | 0.36  | 0.35  | 0.36  | 0.36  | 0.36  | 0.36  | 1.36 | 1.56 | 1.55 | 2.06 | 2.06 | 2.06  | 2.06  | 2.06 | 2.06 | 2.06 |      |
| 18 Heyn and Bauer.              | 3.14 to 3.58          | 4.27 to 3.96     | 0.22± to 0.18   | 0.06± to 0.02  | 0.33± to 0.008          | 0.36  | 0.36  | 0.36  | 0.36  | 0.36  | 0.36  | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62  | 0.62  | 0.62 | 0.62 | 0.62 |      |
| 28 Goorens and Gatoowsky.       | 3.00 to 3.96          | 4.27 to 3.96     | 0.12 to 0.18    | 0.02 to 0.008  | 0.33± to 0.008          | 0.36  | 0.36  | 0.36  | 0.36  | 0.36  | 0.36  | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36  | 0.36  | 0.36 | 0.36 | 0.36 |      |
| Osmund. <sup>b</sup>            | 3.00 to 3.96          | 4.27 to 3.96     | 0.12 to 0.18    | 0.02 to 0.008  | 0.33± to 0.008          | 0.36  | 0.36  | 0.36  | 0.36  | 0.36  | 0.36  | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36  | 0.36  | 0.36 | 0.36 | 0.36 |      |
|                                 |                       |                  |                 |                | 0.008 to 0.04           | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18  | 0.18  | 0.18 | 0.18 | 0.18 |      |

[ 17 ]

In all four of these series given in Table III. the cast-iron was cooled slowly from the molten state to the temperature indicated at the top of the several columns, and then quenched in water. In Series 28 the cast-iron, which when quenched at the beginning of the eutectic freezing contained 1.89 per cent. of graphite, was cooled much more slowly than the other, which then had only 1.05 per cent. In this series the temperatures given represent those of the furnace itself rather than of the iron experimented on. This was in such small quantity, only 2 g., that its retardation in freezing could have little effect on the temperature of the thermo-couple, which therefore outran the cooling of the iron. Hence the actual temperature of the iron was above that here given. The assertions that the iron was "At the beginning," or "At the end of the eutectic freezing," are based on direct observation of the physical condition of the iron at the time of quenching.

<sup>a</sup> The temperature which I have here taken as the eutectic freezing-point, 1,105°, is that at or about which the freezing of the graphite seems to end. It begins at about 1,115°. See Heyn and Bauer, *Stahl und Eisen*, vol. xxvii, No. 44, p. 1586, column 2, lines 6 to 11 (Oct. 30, 1907).

<sup>b</sup> M. Osmund does not give the eutectic freezing-point, which, indeed, was not then recognised. But he noticed a retardation in cooling between 1,085° and 1,130° which very probably represents this point. It is taken here at 1,120°. *Etudes Metalurgiques*, from *Annales des Mines*, vol. xiv, 8th Series, p. 49 (July-August, 1888).

at 11° below the apparent end of the freezing, indicates that the eutectic which actually froze was nearly all cementite-austenite, and in but very small part, if at all, graphite-austenite. The very rapid increase in the graphite-content as the quenching-temperature sinks farther to 18°, 20°, 30°, and 31° below the end of the freezing, is far too great to be explained by the decrease in the solubility of carbon in the austenite, and consequent precipitation of carbon from that austenite, and hence must be due to the change of the eutectic cementite into graphite,  $Fe_3C = Gr. + austenite$ , an inference which is confirmed by the micrographs. In these the cementite-austenite eutectic diminishes rapidly in volume as the quenching-temperature is lowered, and is replaced by graphitiferous nests.

The quantitative results in Series 28 of Goerens and Gutowsky are less conclusive, because the excess of graphite at the end over that at the beginning of the eutectic freezing might represent only direct formation of the graphite-austenite eutectic from the molten state. The same objection applies to the evidence of their micrographs, even those which at first seem most favorable to the theory of the formation of graphite out of the eutectic cementite. Thus about half of their cast-iron No. 21, cooled in 7 min. from 1,250° to 1,100° and then quenched, consisted of cementite-austenite eutectic; the other half consisted of primary austenite and graphitic spheres. But their exactly similar No. 22, cooled in 8 min. from 1,250° to 1,080° and then quenched, had none of this cementite eutectic. The place where it had been was now filled with a graphitiferous mass. It seems to me probable that part of the cementite-austenite eutectic found in No. 21 represented metal already solid at the moment before quenching, and hence that its absence in No. 22 implies that in the cooling from 1,100° to 1,080° this cementite had graphitized. But this is only an inference, and not a necessary conclusion, because it is possible to argue that the cementite-austenite eutectic of No. 21 represents solely the metal still molten at the instant before quenching, and that the metal solid at that same instant was free from cementite, so that the freedom of No. 22 from cementite-austenite eutectic means only that the slow cooling from 1,100° to 1,080° allowed the iron, molten at 1,100°, to freeze as graphite-

austenite eutectic instead of freezing as cementite-austenite eutectic, as it did in the quenching of No. 21 at 1,100°.

§ 13. *Can eutectic graphite form directly from the molten state?* The language of Goerens and Gutowsky might be taken to mean that, in their opinion, the graphite which forms in and near the freezing-range forms solely from the decomposition of the eutectic cementite.<sup>13</sup> But of this I find no proof either in their work or elsewhere. Indeed, the structure shown in such a micrograph as Fig. 5 (by Professor Campbell) seems clearly that of a true graphite-austenite eutectic, *i.e.*, one formed

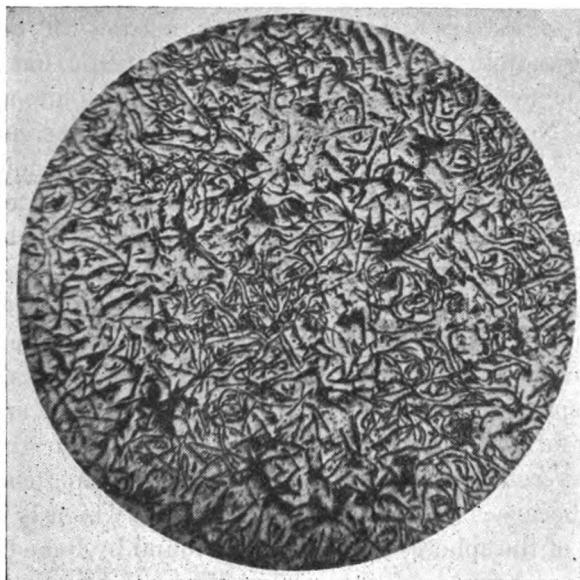


FIG. 5.—THE GRAPHITE-AUSTENITE EUTECTIC. PROFESSOR WM. CAMPBELL.

direct from the molten state and not from the decomposition of cementite. Goerens and Gutowsky repeatedly speak of finding in their cast-irons a "graphite-eutectic," for instance, an "extraordinarily fine" one in their No. 18; and their No. 22, referred to just above here, consists solely of primary austenite and "partly lamellar graphite-eutectic."<sup>14</sup> It does not seem to me that a pseudomorph, a metamorphic mass formed from the decomposition of the cementite-austenite or any other eutectic,

<sup>13</sup> *Metallurgie*, vol. v., No. 5 (Mar. 8, 1908), first lines of p. 146.

<sup>14</sup> *Idem*, pp. 141-2.

can be spoken of as a graphite-eutectic at all, because this term should be applied solely to a true graphite-eutectic, formed as such direct from the molten state.

Here let interpretation be most cautious. Though much of the graphite probably springs from cementite, some may be part of a true graphite eutectic, as the results of Goerens and Gutowsky themselves suggest. Thus, in describing their experiment 18, in which cast-iron quenched at  $1,135^{\circ}$ , the beginning of the eutectic freezing-range, contained spheres of "extraordinarily fine graphite eutectic," they point out the extremely important fact, mentioned in § 48, that the prima-austenoid pine-trees are crossed with needles of cementite where they adjoin the cementite-austenite eutectic, but are free from these needles where they adjoin the graphite-austenite eutectic. Now, if this latter were derived from the cementite-austenite eutectic, then the pine-trees of prima-austenoid which it adjoins should have been pierced by these cementite needles at the time when the assumed cementite-austenite eutectic existed there and before it had changed into this present graphite-austenite eutectic, and these needles should still be present.

Evidence of the formation of the graphite-austenite eutectic direct from the molten state is given by Dr. Benedicks,<sup>16</sup> in the shape of spherulites projecting into a vug in cast-iron, and hence evidently formed from the molten state. It is clear that these spherulites consist, at least in large part, of graphite-austenite eutectic, because of their general appearance, which is identical with that of the spheres of this eutectic found by Benedicks and others in cast-iron, and especially because they contain plates of graphite which actually project into the vug, and hence cannot have been formed by the decomposition of cementite.

§ 14. *Another view of the order of solidification.* Prof. William Campbell indeed infers from the structure shown in Fig. 6 that the graphite-austenite masses represented by the dark spheres or circles must have formed earlier than the cementite-austenite eutectic, *A*, shown beside them. This he infers from the fact that the cementite-austenite eutectic surrounds these spheres. But this is hardly conclusive. True, if these spheres form

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<sup>16</sup> *Metallurgie*, vol. iii., p. 470-1 (No. 14, July 22, 1906), and Micrograph 17, facing p. 432 (No. 13, July 8, 1906).

direct from the molten state, their shape suggests their preceding the cementite-austenite eutectic, because it is not a shape likely to be left between the dendrites of an older formation. Yet these spheres may not have formed from the molten state at all, but through the metamorphosis of the earlier formed cementite-austenite eutectic. This may well have been true in case of the graphitic spheres shown in the micrographs of Goerens and Gutowsky, of successive specimens of like cast-iron quenched at different temperatures just below the eu-

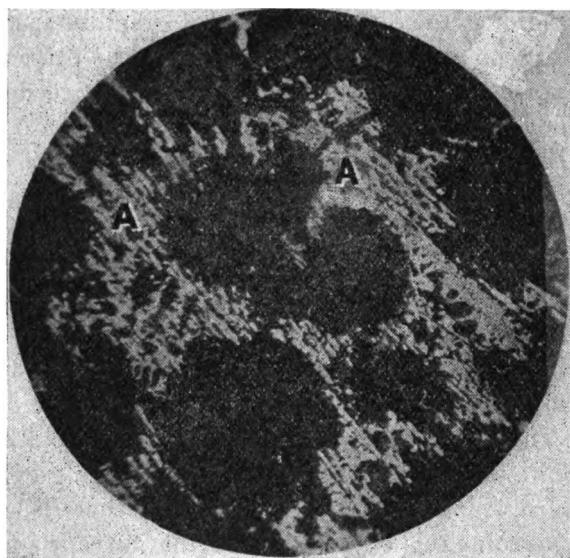


FIG. 6.—CAST-IRON. PROFESSOR WM. CAMPBELL.

The dark circular areas appear to be the graphite-austenite eutectic; the light striped ones, A, the cementite-austenite eutectic.

tectic freezing-point. As the quenching-temperature was progressively lowered, these graphite-bearing spheres came into existence when it had fallen to below the eutectic freezing-point, and gradually increased in volume until, at the apparent end of the freezing, they formed the whole mass of the steel. (Their experiment 22.) Whatever allowance we may make for the lag of the cooling of the cast-iron behind that of the pyrometer's thermo-couple, it is extremely probable that part at least of the growth of these spheres took place after the end of the freezing, and therefore by feeding on the earlier formed

cementite-austenite eutectic. But if this was the way in which this part of the growth of these spheres took place, why may it not be the way in which the whole of that growth took place? It is in general unsafe to deduce relative age from the relation of envelope and kernel, because, though the kernel is very often older than its envelope, yet sometimes the envelope is the senior of the kernel, both in metallography and in mineralogy.

But if Professor Campbell's inference should turn out to be true, we could easily understand that, with progressively increasing rigidity, the formation of the graphite-austenite eutectic might come to arrest itself through the pressure which the bulkiness of its graphite sets up, and be succeeded by the formation of cementite-austenite eutectic.

§ 15. *The bulkiness of graphite argues for its stability.* Beyond this it is but natural from an important consideration that graphite should be the more stable. It is a well-established rule that pressure in and by itself favors the formation of the less bulky of two phases.<sup>16</sup> Now the change from the state of cementite into that of the bulky graphite implies much expansion. But this expansion must necessarily set up stress within the solid metal, and thus be resisted by the pressure which it itself sets up. Thus the very fact that this change from cementite into graphite does take place in spite of its being opposed by the pressure which it creates, argues that there is a force at work to overcome this opposition, and that force is a manifestation or symptom of the greater stability of the graphitic than of the cementite state.

It is as when my cane, nearly upright and leaning against the edge of my table, is toppled over by gravity and thrown to the floor in spite of the frictional resistance of the table which tends to prevent its starting; the fact that in spite of this

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<sup>16</sup> Jones, *The Elements of Physical Chemistry*, Macmillan, 1903, p. 514. "Increase in pressure diminishes the volume, and therefore favors the formation of that system which occupies the smaller volume. Equilibrium is, then, displaced by increase in pressure toward the system which occupies the less volume."

Le Chatelier, *Les Équilibres Chimiques*, p. 210. "Toute variation d'un facteur de l'équilibre amène une transformation du système qui tend à faire éprouver au facteur considéré une variation de signe contraire à celle qu'on lui a communiquée."

"C'est-à-dire que toute élévation de température provoque une réaction avec absorption de chaleur, toute élévation de pression une réaction avec diminution de volume, . . . ."

frictional resistance it moves from the nearly upright to the horizontal position is proof that the latter is the more stable.

This conception helps us to understand why this mill, if it does grind exceeding small, yet grinds so slowly; and further why it is that the shifting into the graphitic state is more rapid at high temperatures. Is it not this? The very beginning of the formation of the bulky graphite out of the compact cementite sets up pressure, which arrests further formation of graphite until the plastic mass has so far flowed under the pressure as to relieve it, and reduce it to such a mildness that it no longer arrests the further formation of graphite. Then a new lot of carbon forms graphite, and sets up new pressure, which temporarily arrests the graphite-forming, and so forth. At very high temperatures, approaching the melting-point, the metal is so soft and plastic that it yields easily and rapidly to this pressure, with the consequence that the formation of graphite is much less strongly opposed, and hence goes on much faster, than at lower temperatures.

§ 16. *Cases in which cementite changes into graphite.* I will now cite twelve cases (A to L) in which heating changed into graphite part of the carbon which was initially present as cementite. In five of these (A to D and L) the proportion thus changed was very large.

(A) *Bell*<sup>17</sup> increased the graphite-content of white cast-iron from 0.374 to 1.79, or by 1.42 per cent., without important change in the total carbon-content, by a thirteen-day heating in the hot-blast stove of an iron blast-furnace.

(B) *Royston*,<sup>18</sup> by heating iron, originally containing 3.85 per cent. of combined carbon and no graphite, to 1,030° rapidly and quenching it, transferred 2.35 per cent. of the carbon to the graphitic state, leaving 1.50 per cent. of it in combination.

(C) *Brustlein*,<sup>19</sup> by re-cementing blister-steel which originally contained 1.70 per cent. of carbon, all combined, transferred 1.38 per cent. of this carbon to the graphitic state.

(D) *Forquignon*,<sup>20</sup> by reheating iron containing originally 3.27 per cent. of carbon, all combined, transferred 1.21 per

<sup>17</sup> *Principles of the Manufacture of Iron and Steel*, p. 159 (1884).

<sup>18</sup> *Journal of the Iron and Steel Institute*, vol. li. (1897, No. I.), p. 166.

<sup>19</sup> Osmond, *Contribution a l'Etude des Alliages*, p. 374 (1901).

<sup>20</sup> *Idem*, p. 378.

cent. of the carbon to the state of graphite in 72 hr. and 1.69 per cent. in 144 hours.

(E) *Wüst and Schlosser*,<sup>21</sup> on heating white cast-iron, which was initially nearly free from graphite, at different high temperatures for 3 hr. and then apparently cooling slowly, found that the carbon had shifted from the combined to the graphitic state to a degree which increased in general with the temperature and with the silicon-content. Their results are condensed in Table I. With even as little as 0.05 per cent. of silicon a little graphite formed at 1,000°. With 0.13 per cent. of silicon the formation of graphite occurred at 900°. With 2.12 per cent. of silicon graphite formed at a moderate rate even at 600°, and with 3.15 per cent. it formed rapidly at 600°. A very remarkable result which they reached was that the formation of graphite was in one case practically as rapid at 700° and in another case at 600° as at any higher temperature. In the former case the cast-iron contained 2.12 per cent. of silicon, in the latter 3.15 per cent.

(F) *Arnold* found that, on repeatedly cementing steel, much of the carbon passed to the graphitic state.

(G) In this connection it is of interest to note the results of *Charpy and Grenet*.<sup>22</sup> They found that, once the transfer of carbon from the combined to the graphitic state has started, it goes on at temperatures below that necessary to induce it in a graphiteless iron, quite as a crystal of sodium sulphate immersed in a supersaturated solution of that salt causes rapid solidification, *i. e.*, a rapid passage from the unstable supersaturated liquid state to the stable solid crystallized state, by "nucleus action."

(H) *Charpy* found that though cementation at 650° in potassium cyanide gives rise to cementite without any graphite, yet at higher temperatures the cementite is decomposed and changed into graphite. By cementing in illuminating gas and in carbonic oxide he reached the following results:<sup>23</sup>

<sup>21</sup> *Stahl und Eisen*, vol. xxiv, No. 19, p. 1120 (Oct. 1, 1904).

<sup>22</sup> *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, vol. cii., p. 401 (1<sup>e</sup> semestre, 1902).

<sup>23</sup> Sur la Cémentation du Fer, *Comptes Rendus*, vol. cxxxvi., No. 17, p. 1000 (Apr. 27, 1903); *Iron and Steel Magazine*, vol. viii., No. 4, p. 301 (Oct., 1904).

TABLE IV.—*Charpy's Experiments in Cementation.*

| Material Treated.                    | Cemented in.         | Length of Time. | Temper-<br>ature. | Carbon Absorbed.       |                                 |
|--------------------------------------|----------------------|-----------------|-------------------|------------------------|---------------------------------|
|                                      |                      |                 |                   | Graphite.<br>Per Cent. | Combined<br>Carbon.<br>Per Cent |
| No. 1. Steel of 0.09 C., 3 mm. diam. | Illuminating gas.    | 64 hours.       | 1,000°.           | 7.66                   | 0.66                            |
| No. 2.                               |                      | 2 hours.        | 900°.             |                        | 3.27                            |
| No. 3.                               |                      | 4 hours.        | 900°.             |                        | 4.90                            |
| No. 4.                               | Pure carbonic oxide. | 1½ hours.       | 1,000°.           |                        | 2.66                            |
| No. 5.                               |                      | 36 hours.       | 1,000°.           | 8.27                   | 1.00                            |

In later trials, on cementing apparently very pure Swedish wrought-iron in wood-charcoal at 1,000°, he found the following percentage of carbon in the product:<sup>24</sup>

| Total Carbon.<br>Per Cent. | Graphite.<br>Per Cent. | Combined Carbon<br>by Difference.<br>Per Cent. |
|----------------------------|------------------------|--|
| 2.50                       | 1.40                   | 1.10   |
| 3.10                       | 2.21                   | 0.89   |

(I) *Saniter*,<sup>25</sup> and also *Mylius, Förster, and Schöne*,<sup>26</sup> give us further instances of the change from cementite into graphite. Saniter found that cementite, isolated from the iron, formed graphite on heating to 800°, and on melting yielded a graphitiferous metallic button containing 4.27 per cent. of carbon. Mylius, Förster, and Schöne found that this isolated cementite, on melting, formed graphite. But, as Benedicks<sup>27</sup> properly points out, this case is of less weight than the others, because the cementite, in being isolated from the iron, is likely to become partly decomposed, and thus to lose in stability, so that it might then change over into graphite under conditions which would not cause the undecomposed cementite to change thus.

(J) *Tiemann's* results may here be considered. Starting with iron wholly free from silicon and containing 4.271 per cent. of carbon as cementite and 0.255 per cent. as graphite, he failed to transfer any of his carbon from the cementite to

<sup>24</sup> *Revue de Métallurgie*, vol. v., No. 2, *Mémoires*, p. 78 (Feb., 1908).

<sup>25</sup> *Journal of the Iron and Steel Institute*, vol. lli. (1897, No. II.), p. 115.

<sup>26</sup> *Zeitschrift für anorganische Chemie*, vol. xiii., p. 38 (1897).

<sup>27</sup> *Metallurgie*, vol. iii., No. 13, p. 429 (July 8, 1906).

the graphitic state even on long heating to temperatures between 906° and 1,116°. But when 0.75 per cent. of silicon was present, his graphite, which in this case was initially 0.938 per cent., rose to 1.69 per cent. on heating to 975°, and to 2.795 per cent. on heating to 1,125°.<sup>28</sup>

(K) *Prof. William Campbell* found that graphite formed in steel of 1.61 and of 1.72 per cent. of carbon on heating to 1,070°, in steel of 2.04 per cent. carbon on heating to 1,200°, and in steel of 1.94 per cent. carbon on heating to 950°, in each case followed by slow cooling.<sup>29</sup>

(L) *Arnold and Mc William* found 1.38 per cent. of graphite in steel initially of 1.80 per cent. carbon, after holding it at about 1,000° for about 70 hr. and cooling thence extremely slowly.<sup>30</sup>

It has been a tradition in Sheffield for many years, to my knowledge, that the separation of graphite in high-carbon steel is caused either by too low a finishing temperature, *i.e.*, by continuing the rolling or hammering till the temperature has sunk unduly low, or by unduly long and high heating for annealing. A possible explanation of the effect of cool rolling is that the strong internal tension (the opposite of pressure), which it causes, may favor the formation of the bulky graphite. Graphite, once started locally thus, might by nucleus action spread throughout much of the cross-section. That cool rolling does cause severe internal tension in pieces of appropriate shape is shown not only by the Mannesmann process of tube-rolling, but by common experience in hollow forging. I unintentionally developed a large central pipe in hammering in the cold square bars of even so ductile a substance as copper.

(M) In *Sauveur's* experiment the combined carbon of cast-iron fell from 1.288 to 0.942, or by 0.346 per cent., and the graphite from 3.066 to 1.928, or by 1.138 per cent., on holding at 1,000° for 5 hr. and cooling slowly.<sup>31</sup> It is on the whole probable that most of the carbon which became oxidized in this experiment existed at the time of its oxidation as graphite, and hence that some at least of the 0.346 per cent. of decrease

<sup>28</sup> *Metallographist*, vol. iv., No. 4, p. 319 (Oct., 1901).

<sup>29</sup> *Proceedings of the American Society for Testing Materials*, vol. vi., pp. 230 to 234 (1906).

<sup>30</sup> *Journal of the Iron and Steel Institute*, vol. lxviii. (1905, No. II.), p. 46.

<sup>31</sup> *Journal of the Iron and Steel Institute*, vol. lxxii. (1906, No. IV.), p. 506.

of combined carbon represents a transfer to the graphitic state. The case offers no strong evidence in either direction. I give it only to show that it does not conflict with the present theory.

§ 17. *Phenomena which at first seem to oppose the present or double diagram theory.* Cases in which graphite is changed into cementite by heating at first seem to oppose this theory strongly, because whatever change occurs should be towards greater stability. Cases in which carbon on first entering the solid iron, either from without, as in the cementation process, or from within, as in the solidification of molten cast-iron, forms cementite rather than graphite do not oppose this theory, because, as already pointed out, the metastable form is usually the one most readily entered. Cases of both these kinds will now be given.

(N) *Cases in which cementation generates cementite instead of graphite.* The familiar fact that the carbon of blister-steel made by the cementation process exists chiefly in the state of cementite is confirmed by the direct experiments of *Arnold*,<sup>32</sup> whose micrographs of blister-steel show no suggestion of graphite, even when the carbon-content is as high as 1.90 per cent., and of *Brustlein*, who reports that all of the 1.70 per cent. of carbon in a specimen of blister-steel was combined, and therefore must have existed as cementite.<sup>33</sup>

(O) *Margueritte*<sup>34</sup> introduced 6.60 per cent. of carbon in one case and 6.55 per cent. in another into finely divided metallic iron made from the oxalate, by cementation for 3 hr. in carbon monoxide at a low cherry and a bright cherry heat respectively. These color-names correspond to temperatures of 635° and 843° respectively on the scale of White and Taylor; but it is far from certain that these are the temperatures to which Margueritte refers. The fact that the carbon-content of Margueritte's cemented iron was almost exactly that of cementite (theoretically 6.67 per cent.), certainly suggests very strongly that his cementation formed cementite. The case is a very striking one in view of the fact that Margueritte could hardly have

<sup>32</sup> *Journal of the Iron and Steel Institute*, vol. liv. (1898, II.), p. 185; Micrograph No. 10 (Plate XX).

<sup>33</sup> *Osmond, Contribution a l'Etude des Alliages*, p. 374 (1901).

<sup>34</sup> *Comptes Rendus*, vol. lix., No. 18, p. 726 (Oct. 31, 1864).

suspected the existence of a compound with the formula of cementite.

(P) *Charpy*,<sup>35</sup> confirming Margueritte's results, actually converted two lots of steel filings initially containing 0.09 per cent. of carbon into cementite by heating them at about 650° in potassium cyanide, in one case for 85 hr., in the other for 110 hr. In both cases the steel thus cemented contained 6.72 per cent. of carbon, and therefore must have been converted into cementite, because this is practically the carbon-content of cementite, and because the mass dissolved completely in acid, leaving no trace of graphite.

(Q) *Dr. C. Offerhaus* and I heated powder of pure electrolytic iron, made by Professor Burgess, for 50 hr. in potassium cyanide at about 650°.

Samples taken out at different periods had the following composition :

| Time from the beginning, . . . | 14 hours<br>Per Cent. | 31½ hours<br>Per Cent. | 50 hours<br>Per Cent. |
|--------------------------------|-----------------------|------------------------|-----------------------|
|                                |                       |                        |                       |
| Combined carbon, . . . .       | 5.19                  | 5.74                   | 6.75                  |
| Graphite, . . . .              | 0.11                  | 2.38                   | 2.88                  |
| Total carbon, . . . .          | 5.30                  | 8.12                   | 9.63                  |

(R) *Saniter*,<sup>36</sup> by cementing pure iron wire in charcoal at about 900°, gave it a carbon-content of 2.95 per cent., of which 2.42 per cent. was combined.

§ 18. (S) *Cases in which graphite changes into cementite.* A steel with which *Osmond* experimented contained initially 1.38 per cent. of graphite and only 0.24 per cent. of combined carbon. It was therefore equivalent to low-carbon steel contaminated with much graphite, and on heating and cooling underwent only the slight retardations at  $A_1$  and  $A_3$ , characteristic of such steel. On repeating his heatings and coolings the retardations progressively lengthened, and finally became those of a normal high-carbon steel.<sup>37</sup>

Now as the retardation at  $A_1$  is due to the change of carbon back and forth between the states of austenite and pearlite and cannot be caused by graphite, we have here clear evidence that

<sup>35</sup> *The Iron and Steel Magazine*, vol. viii., No. 4, p. 305 (Oct., 1904.)

<sup>36</sup> *Journal of the Iron and Steel Institute*, vol. lii. (1897, No. II.), p. 122.

<sup>37</sup> *Contribution a l'Etude des Alliages*, p. 375-6 (1901).

the graphite was gradually changed into combined carbon, which in the steel when cold would of course exist as cementite.

(T) *Heyn and Bauer*,<sup>38</sup> on reheating slowly cooled cast-iron of 1.46 per cent. of silicon, 1.32 per cent. of combined carbon, and 2.01 per cent. of graphite, to different high temperatures, holding it there for 30 min., and then quenching it in cold water, found that the combined carbon-content had increased materially. Their results are given in line 17A of Table I., and are condensed in Table V.

TABLE V.—*Change from Graphite into Combined Carbon.*  
*From the Data of Heyn and Bauer.*

| Temperature to which the cast-iron was reheated before quenching..... | 800°.             | 900°.             | 1,180° to 1,200°. |
|---|-------------------|-------------------|-------------------|
| Combined carbon-content after this treatment.....                     | Per Cent.<br>1.52 | Per Cent.<br>1.47 | Per Cent.<br>1.70 |
| Increase of combined carbon-content due to this treatment.....        | 0.20              | 0.15              | 0.38              |

(U) *Royston*,<sup>39</sup> starting with malleable cast-iron, all of the carbon of which was graphitic, made 0.85 per cent. of this carbon re-combine at 720°, and 1.50 per cent. of it re-combine at 1,030°, in each case in three hours. See § 58, p. 520.

In § 45, p. 514, another case is given in which graphite seems to have changed into cementite.

§ 19. *The change from graphite into cementite reconciled with the greater stability of graphite than of cementite.* But this change from graphite into cementite is readily reconciled with the theory that graphite is the more stable of the two. In the austenite which exists above  $A_1$ , i.e., in regions 4, 5, and 7 of Fig. 1, about 0.90 per cent. of carbon is soluble at  $A_1$ , and 2.20 per cent. at 1,130°. When graphitiferous iron is heated above  $A_1$ , then, part of this graphite may dissolve in the austenite, until this is nearly or quite saturated with carbon for the existing temperature. When the temperature again falls, and with the fall of temperature the solubility of carbon in austenite decreases, this dissolved carbon is precipitated out of the austenite gradually as the temperature sinks towards  $Ar_1$ , at which point the carbon-content should have sunk to 0.90 per cent.,

<sup>38</sup> *Stahl und Eisen*, vol. xxvii., No. 44, p. 1568 (Oct. 30, 1907.)

<sup>39</sup> *Journal of the Iron and Steel Institute*, vol. li. (1897, No. I.), p. 171.

and abruptly on cooling past  $Ar_1$ , when this 0.90 of carbon should fall out of solution as the cementite contained in pearlite. But when the carbon thus falls out of solution, it is perfectly natural that it should re-precipitate in the metastable form as cementite, rather than as graphite, especially in view of the pressure which the formation of the bulky graphite would set up. The very first particles of graphite which formed in this re-precipitation would, by their bulk, set up a pressure which would determine that the next particles which precipitated should form cementite. Thus, the transfer of carbon from the graphitic to the cementite state simply implies that part of the carbon has, in heating, re-dissolved in the austenite, and on its re-precipitation in cooling has separated as cementite.

§ 20. *May solution and re-precipitation explain the change from cementite into graphite?* Here some may say that what is sauce for the goose is sauce for the gander. If we complacently explain the change of carbon from graphite into cementite by saying that the graphite has dissolved in the austenite and then re-precipitated in the form of cementite, why may we not answer that the change of carbon from the state of cementite into that of graphite may be explained by assuming that the carbon of the cementite in like manner dissolved in the austenite, and later re-precipitated as graphite? If dissolving in the austenite and then re-precipitating in a new condition explains the change of carbon from graphite into cementite, why may it not explain the change in the opposite direction from cementite into graphite? And if this change may be explained in this way, then it has no force as evidence that graphite is the more stable form.

To this it may be answered that, whereas solution and re-precipitation do explain readily the change from graphite into cementite, they do not explain quantitatively the change from cementite into graphite, which, therefore, is to be referred to the greater stability of graphite. They explain the change from graphite into cementite, because in all of the cases here recorded the quantity of carbon thus transferred is less than that which the austenite is capable of dissolving on heating and giving up again on cooling—viz., 2.2 per cent. The greatest quantity thus changed is 1.50 per cent., reported by Royston, case (U), above, No. 27 of Table I. But solution and

re-precipitation do not so readily explain the change from cementite into graphite, because the quantity of carbon which thus changes, *e.g.*, 2.35 per cent. in case (B), is greater than the 2.2 per cent. which austenite is capable of thus dissolving. This answer is not in and by itself a very convincing one, and the phenomena of the cementation process which we will now consider make it even less convincing.

§ 21. *Phenomena of cementation.* The principle just discussed, that the carbon which readily dissolves in austenite up to about 2.2 per cent. naturally re-precipitates as cementite rather than as graphite on cooling, explains easily why the carbon which enters the steel in the cementation process habitually exists in the cold steel as cementite rather than as graphite, provided that the quantity of carbon in that cementite does not exceed that which the metal can dissolve at the temperature of cementation, as indeed is usually the case. But what is the mechanism by which the cement-carbon-content may be carried far above that which saturates the austenite with carbon, as in the cases cited above, in which the steel is converted by potassium cyanide into pure cementite to its very core? And when the cement-carbon-content is raised far above 2.2 per cent., as seems to have occurred in Mannesmann's experiments,<sup>40</sup> by heating in charcoal and even in graphite itself, how is the fact that graphite is turned into cementite to a degree far too great to be explained by simple solution and re-precipitation to be reconciled with the theory that graphite is the more stable of the two? M. Osmond gives us a hint from which Dr. Benedicks<sup>41</sup> works out an explanation, which I will now further elaborate.

Once the austenite has become saturated with carbon, at the least cooling and consequent decrease of the solubility of the carbon, part of the dissolved carbon precipitates out as cementite. If the temperature rises ever so slightly, the austenite now exposed to the external cementing graphite is no longer saturated with carbon, and now absorbs additional carbon, which diffuses inwards.

When we first examine this explanation it may seem strained. Picturing to ourselves a piece of steel which has become so far

<sup>40</sup> *Verhandlungen des Vereins zur Beförderung des Gewerbeleisses*, lviii., pp. 38, 40 (1879).

<sup>41</sup> *Metallurgie*, vol. iii., No. 13, p. 439 (July 8, 1906).

carburized that even the central parts contain more carbon than suffices to saturate the austenite, so that even here the austenite contains islands of precipitated cementite, we recognize that, at each rise of temperature, this internal precipitated cementite is sure to compete with the external graphite in the work of supplying to the adjacent austenite the carbon which it is capable of taking because of its increased solvent power for carbon due to that rise of temperature. We ask how, under these conditions, carbon which enters at the outside can by any possibility reach the center of the piece before the demand of that center for carbon shall already have been fully supplied by the local precipitated cementite? By what mechanism, then, can this external carbon raise the carbon-content

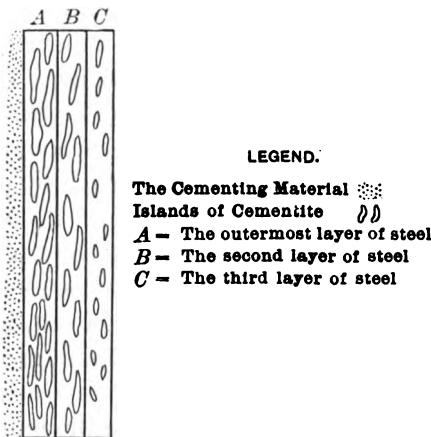


FIG. 7.—THE MECHANISM OF HIGH CEMENTATION.

of the center materially above that which suffices to saturate the austenite?

The answer is a simple one. It is not that at any given rise of temperature any one molecule of carbon rushes from the outside away in to the center, past all the intermediate islands of cementite which are competing with it in the act of carburizing the austenite; but that at each rise there is a wave of carburization surging from the outside to the inside, with but slight centerward translation of the individual molecules of carbon. To understand this easily, consider the three adjoining layers, *A*, *B*, and *C*, Fig. 7, each 0.0001 in. thick, of which *A* is the external layer in contact with the foreign carburizing graphite, and with rather more cementite than *B*,

which in turn has rather more than *C*. At each fall of temperature a little additional cementite is precipitated out of the austenite, to join the islands of cementite already present. At each rise of temperature these islands start to re-dissolve in the austenite. But, because there are more islands in *A* than in *B*, the re-carburizing of the austenite in *A* will be more rapid than in *B*, with the consequence that carbon diffuses from the temporarily more-carburized austenite of *A* into the temporarily less-carburized austenite of *B*; and in like manner carbon diffuses from the austenite of *B* into that of *C*, and so on from the very outside to the very core. Thus there is a wave of carburization which may travel some inches, though the individual molecules of carbon may travel only a fraction of a 10,000th of an inch. At the same time the external graphite competes with the cementite islands of *A* in the work of re-carburizing those microscopic particles of austenite which lie at the outside of *A* in contact with that graphite; and thus it comes about that some carbon enters the piece from the external graphite. By repetition of these waves of carburization and this slight uplicking of carbon from the external graphite it comes about that, after a sufficient number of even extremely slight oscillations of temperature, the carbon-content of the very center may be brought far above that needed to saturate the austenite.

§ 22. *Summary.* However satisfying this explanation of the genesis of cementite in the cementation process may be, the very facts (1) that extraneous graphite thus changes so abundantly into cementite which persists so well, and (2) that even indigenous graphite may thus change into cementite (cases S, T, and U of § 18), show that the mere fact of the change from cementite into graphite in the many cases given (cases A to M, of § 16) is not in itself strong evidence that graphite is the more stable of the two. Nor is there strong evidence to this effect in the fact pointed out in § 20, that the formation of cementite from graphite is explained quantitatively by solution and reprecipitation, whereas the reverse formation of graphite from cementite is not so explained, because the quantity of graphite which thus forms exceeds the quantity of carbon which austenite can dissolve. The force of this fact is lessened by the explanation just given of the change of a still

greater quantity of extraneous graphite into cementite in the cementation process; because this leads us to suspect that, under favoring conditions, the quantity of indigenous graphite which can be changed thus into cementite may exceed the solubility of carbon in austenite. If the change of extraneous graphite into cementite may thus exceed that solubility, why may not that of indigenous graphite? Indeed, the suspicion just referred to is greatly strengthened by the cases examined in §§ 45 and 53, pp. 514 and 520, because in these cases the quantity of carbon which has changed from the graphitic to the cementite state seems to be greater than that which the austenite can dissolve at the temperature actually reached.

Thus the evidence of the greater stability of graphite than of cementite is to be found, not in such facts taken in their nakedness, but rather in the attendant conditions. These are:

1. That the change from cementite into graphite is exothermic, and hence in the direction of greater stability.
2. That this change does take place in spite of the evident opposition to it which the bulkiness of the resultant graphite sets up, through the pressure which its formation must cause.
3. That cementite is habitually the form first assumed by the carbon of solid iron, whether it comes from within, as in the solidification of molten iron, or from without, as in the cementation process; and from the decomposition of this cementite comes part and often the whole of the graphite which eventually forms. This is the habitual order of things, the formation of the metastable first, and of the stable later.
4. That, according to Benedicks' keen observation,<sup>42</sup> whereas there is much microscopic evidence tending to show that cementite often changes into graphite directly without passing through solution in austenite, yet there is no such evidence of a direct change from graphite into cementite. Prof. William Campbell's observations and my own tend to confirm this.
5. That in the regular manufacture of malleable castings, the shifting of carbon from the initial state of cementite into that of graphite is not only certain, every day, in every batch, and one might almost say in every part of every piece treated, but further apparently often exceeds in quantity the percentage (2.2 per cent.) which suffices to saturate the austenite.

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<sup>42</sup> *Metallurgie*, vol. iii., No. 13, p. 433 (July 8, 1906.)

Of these five, the first three seem to me very cogent, while the contributory weight of the last two is considerable.

## PART II.

§ 23. *Topography of the graphite-austenite diagram.* (A) *The freezing-point curves.* Charpy<sup>43</sup> found that the cementite-austenite eutectic freezing-point was very slightly lower than that of the graphite-austenite eutectic, but that the difference was only about  $10^{\circ}$  or  $15^{\circ}$ . This agrees with Le Chatelier's prophecy on this subject, as shown by the relative position of these two eutectic freezing-points in the Roberts-Austen<sup>44</sup> diagram of 1899. But Charpy's determination does not seem to have been very positive.

§ 24. (B) *The transformation-curves.* Just as, when the red- or white-hot iron consists of a mixture of austenite and cementite, the solubility of carbon in the austenite diminishes as the temperature falls, as represented by the curve  $Ar_s$ ,  $Sa$ , of Fig. 1; so it is but natural to assume that, when the metal consists of a mixture of graphite and austenite, there shall be a like decrease in the solubility of carbon with falling temperature, which can be represented in the graphite-austenite diagram by a line analogous to  $Ar_s$ . Further, it is natural to assume that the solubility of carbon in austenite when the phase presented to the austenite is graphite differs from the solubility when that phase presented is cementite.

There has been an important attempt to determine the curve of solubility of graphite in austenite by means of the data of Charpy and Grenet, and the results of this attempt are said to be confirmed by the earlier data of Mannesmann. After explaining the Charpy-Grenet procedure, I will discuss the solubility-curve which has been based on their results, then offer a curve which agrees more closely with them, then discuss the competence of these results as evidence of the position of this solubility-curve, and then consider how far Mannesmann's data actually confirm the curve deduced from the Charpy-Grenet results. After summarizing this discussion, I will next

<sup>43</sup> *Comptes Rendus*, vol. cxli., No. 23, p. 950 (2<sup>e</sup> semestre, 1905).

<sup>44</sup> *Fifth Report to Alloys Research Committee*, read before Institution of Mechanical Engineers, Feb. 9, 1899, Fig. 10, Plate 4, *Proceedings of the Institution of Mechanical Engineers* (1899).

consider what inferences can be drawn from the other data at hand.

§ 25. *The Charpy and Grenet line* is shown in Fig. 8 by the points  $r$ ,  $r'$ , and  $r''$ , which correspond to the following numbers:

| Temperature, Centigrade, . . . . . | $r$  | $r''$ | $r'''$ |
|------------------------------------|------|-------|--------|
| 800°                               | 800° | 900°  | 1,000° |
| 0.70                               | 0.70 | 0.90  | 1.30   |

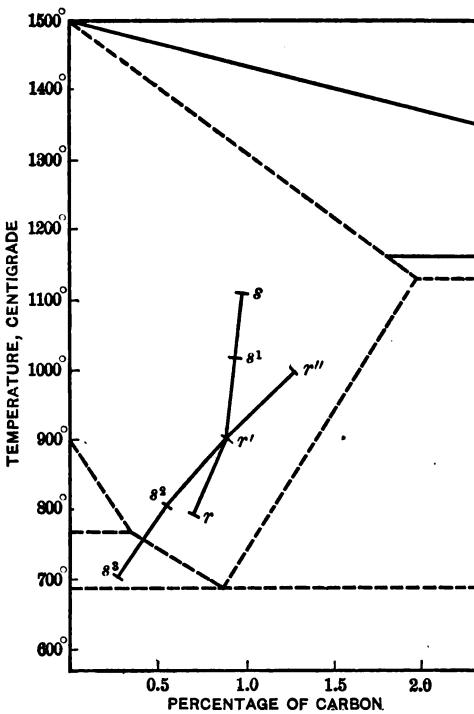


FIG. 8.—SOLUBILITY OF CARBON IN AUSTENITE IN PRESENCE OF GRAPHITE, TOGETHER WITH PARTS OF THE STABLE AND METASTABLE DIAGRAMS FROM FIG. 4.

Their general procedure was, first, to melt cast-iron and granulate it in water, so that all or nearly all of its carbon was initially either combined as cementite or dissolved in the austenite; then to reheat it to a given high temperature,  $T_n$ , and hold it there for a long time with the intention, first, of changing the carbon of the cementite into graphite, and, second, of enabling the carbon initially dissolved in the austenite to fall out of solution as graphite until the remaining austenite was just saturated with carbon; then to quench the iron in cold water

in order to prevent any appreciable further separation of graphite during cooling, and thus to preserve in solution the quantity which had actually remained in solution at  $T_n$ ; then to determine the total carbon and also the graphite; and, finally, to find by difference the carbon which had remained in solution in the austenite. In certain cases the formation of graphite was started by heating the metal close to the melting-point; the metal was then cooled slowly to  $T_n$ , and then quenched, either immediately after reaching  $T_n$  or after staying there for a long time.

Without here passing upon the competency of the data to prove the solubility of graphite in austenite, we may here note that the numbers which Charpy and Grenet get by difference are simply the non-graphitic or agraphitic carbon, which includes both that dissolved in the austenite and any present as cementite; and, further, that even the dissolved carbon, though in spots it is that dissolved in presence of graphite, in other spots would be that dissolved in presence of cementite, if any cementite were present. But let us consider this question later, and here ask only what the results of Charpy and Grenet show on their face.

§ 26. *Discussion of the points  $r$ ,  $r'$ , and  $r''$  of the Charpy and Grenet line.* All the results which Charpy and Grenet reached in this investigation are given in lines 1 to 5 of Table I, p. 526.

§ 27. *Point  $r'$ , solubility at  $900^\circ$ .* All seven determinations of this point made with cast-iron containing either 1.25 or 2.10 per cent. of silicon agree surprisingly. The higher numbers reached with the low silicon-content of 0.80 per cent. are satisfactorily explained away by the great lag due to the smallness of this silicon-content, so that there is no reason here for doubting the position assigned to this point, 0.90 per cent.

§ 28. *Point  $r''$ , solubility at  $1,000^\circ$ .* I do not understand why the position 1.30 per cent. has been assigned to this point. It is clear that the cast-irons initially contained much more combined carbon than is soluble in the austenite, and that, during the exposure to  $1,000^\circ$ , the sum of the cementite-carbon and of the dissolved carbon was decreasing towards the solubility or saturation-point of carbon in austenite. This decrease might or might not bring the total agraphitic carbon-content fully down to the saturation-point; but it certainly could not bring

it below that point. Hence, the lowest result must be taken simply as that which is least in excess of the saturation-point, and hence is the closest approximation to the truth. I cannot see why the number 0.93 per cent. found with iron No. 5 at 1,000° should not be accepted, especially because it is supported in a measure by the number 0.98 per cent. found for iron No. 4 at 1,000°.

§ 29. *Point r, solubility at 800°.* The position assigned, 0.70 per cent., I cannot accept. First, I find no such result recorded. Second, I see no reason for rejecting the number 0.54 found for iron No. 5 at 800°. Indeed, the number 0.43 per cent. found for No. 3 seems to me practically as trustworthy as any of these. This particular specimen, after very slow cooling to 900°, was then cooled completely, and reheated the next day to 900°, and then cooled in 2 hr. to 800°, then held for 2 hr. at 800° and quenched. To this it has been objected that, in cooling below 800°, the carbon-content of the austenite may have fallen below the 800° saturation-point, and this carbon thus rejected may not have been re-absorbed the next day. It seems a fair answer that the austenite had 2 hr. above 800°, and 2 more at 800°, to re-absorb this carbon, and that I know of no evidence that the re-absorption of carbon is less rapid than its expulsion. In this particular case any carbon expelled below 800° would remain very close to the austenite whence it was expelled, because of the slowness of diffusion at these low temperatures, and because it should lie so close it should be re-absorbed quickly. Personally, then, I should adopt 0.43 per cent. as the most probable number; but to avoid all appearance of unfairness to the numbers which I am criticising I adopt 0.54 per cent.

§ 30. *A more reasonable Charpy and Grenet line.* If we plot the points found in this discussion to be the nearest approximations to the truth, 0.90 per cent. for 900°, 0.93 per cent. for 1,000°, and 0.54 per cent. for 800°, and proceed in the same way to select the nearest Charpy and Grenet approximations for 700° and 1,100°, we get the line  $s, s^1, r', s^2, s^3$  in Fig. 8. Personally, I attach little importance to this line, for reasons which I will next explain. But at least it has the merit of being in harmony with the results on which it is based. These numbers are given in Table VI.

TABLE VI.—*A More Reasonable Charpy and Grenet Line.*

| Temperature .....       | 1,100°    | 1,000° | 900° | 800°  | 700°  |
|-------------------------|-----------|--------|------|-------|-------|
| Solubility .....        | 1 per ct. | 0.93   | 0.90 | 0.54  | 0.28  |
| Designation letter..... | $s$       | $s^1$  | $r'$ | $s^2$ | $s^3$ |

§ 31. *How valid evidence do the Charpy and Grenet results give as to the solubility of graphite in iron?* We have now seen that not the line  $r-r'$  but the line  $s-s^3$  is, in fact, indicated by these results. Let us next ask as to the competency of the evidence which these results give, so that we may know what weight to attach to this line  $s-s^3$ .

§ 32. *Definitions.* To facilitate discussion let us, for the purposes of the present paper only, adopt these terms.

$T_n$  = any given temperature for which we are seeking the solubility of carbon in austenite in the presence of graphite, *i.e.*, the saturation-point.

$ST_n$  = the percentage of dissolved carbon which thus just saturates the austenite at  $T_n$ , *i.e.*, the solubility of carbon in austenite at  $T_n$ . In the same way let us call  $ST$  1,000° the solubility at 1,000°, etc.

$AGr$  = the total agraphitic or non-graphitic carbon-content, including the dissolved and the cementite-carbon.

§ 33. *Discussion.* What we are seeking is the solubility of graphite in pure, *i.e.*, silicon-less iron; what the Charpy-Grenet numbers give is the total agraphitic carbon actually present in very siliciferous iron. Those who have accepted these numbers as equal to that solubility have tacitly assumed that  $AGr = ST_n$ , and in doing this have made three separate assumptions:

- (A) That the silicon-content does not affect the solubility;
- (B) That the agraphitic carbon is all dissolved carbon; and
- (C) That this dissolved carbon actually saturates the austenite at  $T_n$ .

With regard to assumption (A), it is of course admitted that, within limits, the more silicon is present the more readily does carbon pass out of combination as cementite or out of solution in austenite into the state of graphite; but it is held by some that the action of silicon is purely catalytic, not changing the true solubility of carbon in austenite, but only lessening the lag, and thus hastening compliance with that solubility, or, in other words, hastening the separation as graphite of any carbon

actually retained in solution by lag, in excess of the true solubility or saturation-point,<sup>45</sup> and also hastening the change from the metastable cementite to the stable graphite. Neither line,  $r$ ,  $r'$ ,  $r''$ , nor  $s$ ,  $s^*$ , has the least claim to accuracy unless this assumption is made, because every point in each line rests upon one or more determinations made with iron containing an important quantity of silicon. In § 43 the influence of silicon is discussed.

Assumption (B) is that of the three forms of carbon: (1) carbon combined as cementite,  $Fe_3C$ ; (2) carbon dissolved in the austenite; and (3) free graphite, only the second and third are present, so that the whole of the great quantity of cementite which, because of the initial absence of graphite, we infer must have been present initially, has disappeared, either changing into graphite or dissolving in the austenite. It is only on this assumption that either  $r$ ,  $r''$  or  $s$ ,  $s^*$ , or any other curve of the solubility of graphite in austenite, can be based on the Charpy-Grenet results. If any cementite is present, then the agraphitic carbon, instead of equaling the carbon dissolved in the austenite in the presence of graphite, as has to be assumed in order to infer the solubility of carbon in austenite in presence of graphite from the Charpy-Grenet data, really represents three distinct things: (1) carbon present as cementite; (2) in certain microscopic spots carbon dissolved in austenite in presence of that cementite; and (3) only in certain other microscopic spots, that which we are seeking, the carbon dissolved in austenite in presence of graphite.

Assumption (C) is that the austenite, which is justly assumed to have been supersaturated with carbon when first cooled to  $T_n$ , has, in the stay at  $T_n$ , actually expelled all carbon in excess of the true saturation-point, so that the combined carbon found actually represents the saturation-point, or the true solubility of carbon in austenite in the presence of graphite at  $T_n$ .

To assumptions (B and C), taken jointly, it seems a reasonable answer that, if the experience of centuries with the process of annealing malleable castings has shown that two days at full

<sup>45</sup> . . . "die Graphitbildung wird durch steigenden Si-Gehalt stark beschleunigt, aber der Endzustand wird durch Si nicht beeinflusst, wie besonders die Kurven für 1.20 % Si und 2 % Si bei 900° lehren." Benedicks, *Metallurgie*, vol. iii., No. 13, p. 432 (July 8, 1906).

heat are needed to bring about even the incomplete change from cementite into graphite, which suffices for the commercial needs of the process, and if even then an extremely slow cooling is needed to make the content of carbon dissolved in the austenite fall near enough to the saturation-point for commercial purposes, it is hardly safe to assume that the 4-hr. periods of Charpy and Grenet have sufficed to do these same things with the extreme thoroughness needed for scientific purposes, in default of direct evidence that they have sufficed. Further, we have seen in § 18 how readily the carbon, even when it has once become graphitic, shifts back into the cementite state. Hence I infer that assumption (B) is very rash.

Thus all three of these necessary assumptions are at least questionable.

Now any error in assumption (A) tends to bring the Charpy-Grenet results below the true solubility; and any error in either assumption (B) or (C) tends to bring those results above the true solubility. Hence the solubility, instead of being equal to those results as has been assumed, may, because of the errors in these assumptions, be either greater or lesser than those results, and by an unknown and indeterminate amount.

§ 34. *Mannesmann's results.* In confirmation of the trustworthiness and accuracy of the position of the line  $r, r', r''$ , it has been asserted that, representing as it does the results of Charpy and Grenet, it is confirmed by those of Manesmann reached in a wholly different manner.<sup>46</sup> That Manesmann's manner was wholly different is true, but so far as I can see his results not only do not confirm those of Charpy and Grenet, but do not bear on them in the remotest possible way.

In trying to test the truth of the then general opinion that the carbon-content could not be raised above 2 per cent. by cementation without melting the resultant cast-iron, Manesmann found that, by cementing wrought-iron in charcoal, he could make not only steel and white cast-iron of any and every carbon-content up to 4.76 per cent., but also both light gray and dark gray cast-iron, and in every case wholly without fusion,

<sup>46</sup> "Von grossem Interesse ist, dass die drei Löslichkeitswerte des Graphits, die man aus den schon erörterten Bestimmungen Charpy und Grenets gewinnt, mit denjenigen auf ganz anderem Wege von Manesmann erhaltenen vorzüglich übereinstimmen." Benedicks, *Metallurgie*, vol. iii., No. 13, p. 435 (July 8, 1906).

whence he inferred that as much carbon can be introduced by cementation as by fusion.<sup>47</sup> He then sketched a curve, which I here reproduce as *AB* in Fig. 9, showing, first, how the percentage of carbon which can thus be introduced increases with the temperature, and, second, that the temperature needed to raise the carbon-content above, say, 4.75 per cent., is so near the melting-point of the resultant cast-iron (as shown by the melting-point curve *CD*) that it is extremely difficult to carry the carburization farther without melting the iron.

§ 35. *Mannesmann's curve a freehand sketch.* All the internal evidence tends to show that this, his curve *AB* of the attain-

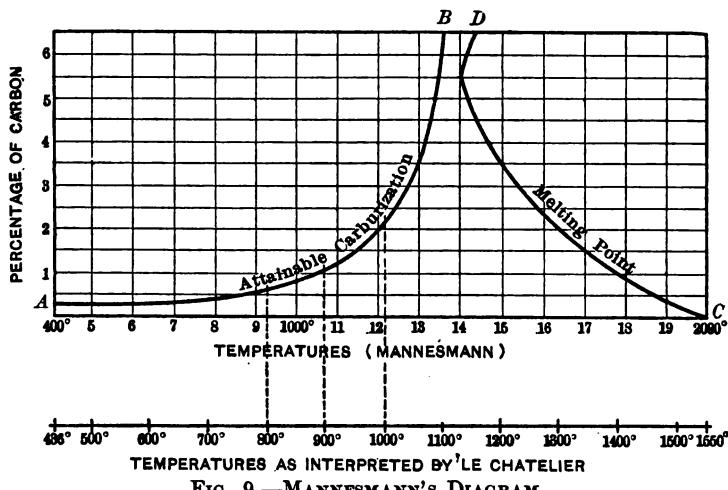


FIG. 9.—MANNESMANN'S DIAGRAM.

able degree of carburization, does not pretend to be anything more than a sketch. In the first place, there are no numerical measurements of temperature, nor, indeed, estimates of temperature in the text. He refers only to "yellow heat," "light yellow heat," and other like color-names; he never in the whole paper gives a single temperature in degrees, and he never attempts to identify the temperature of any of his experiments by saying that it was the melting-point of some known substance, or in any like way.

In the second place, the perfect smoothness of his curve, without a single dot, spot, or cross to indicate the result of any

<sup>47</sup> *Verhandlungen des Vereins zur Beförderung des Gewerbefleisses*, lviii., p. 31 (1879). This very valuable paper was written by Mr. Mannesmann at a very early age.

one determination, in itself goes to show that this curve was only a sketch, and made no pretense to accuracy.

In the third place, though his actual results seem to have reached only to 4.76 per cent. of carbon, his curve itself runs up to 6.5 per cent. (misnumbered in the original), so that the part between 4.76 and 6.50 per cent. seems to be extrapolated, and therefore, of course, nothing but a fancy sketch. But this extrapolated part is of exactly the same smoothness and general appearance as that below 4.76 per cent., so that it is not safe to assume that this latter part is anything more than a fancy sketch.

In weighing evidence it is a fundamental rule that the burden of proof of validity is on him who presents the evidence. No such proof is here offered, and in view of the *prima facie* indications that the curve is nothing but a sketch, it should, in my opinion, be accepted only as a sketch.

§ 36. *Mannesmann's curve does not agree with that of Charpy and Grenet.* If, for argument's sake, the curve is accepted as accurate and trustworthy, it still fails to confirm the Charpy and Grenet curve, for the excellent reason that it differs radically from it, as is seen on comparing lines 1 and 3 in Table VII.

TABLE VII.—*Comparison of the Charpy and Grenet Data with Those Attributed to Mannesmann.*

| Temperature.....  | 800°<br>Per Ct. | 900°<br>Per Ct. | 1,000°<br>Per Ct. |
|---|-----------------|-----------------|-------------------|
| (1) Results claimed from Charpy and Grenet.....   | 0.70            | 0.90            | 1.30              |
| (2) Results from Charpy and Grenet as modified by the present writer.....                       | 0.54            | 0.90            | 0.93              |
| (3) Results from Mannesmann (A) using his temperature-scale.....                                | 0.45            | 0.55            | 0.75              |
| (4) (B) Applying Le Chatelier's correction <sup>a</sup> to Mannesmann's temperature-scale ..... | 0.60            | 1.05            | 2.15              |

<sup>a</sup> *Le Chatelier's Correction.*—In order to make allowance for Mannesmann's evident errors in temperature, Le Chatelier (*Contribution a L'Etude des Alliages*, p. 382), changes Mannesmann's melting-point of pure iron to 1,550°, assumes that his 500° is accurate, and divides the intermediate temperatures up proportionally.

If it is pleaded that some correction should be made in the temperature to allow for Mannesmann's evidently wrong temperature-scale, the question immediately arises, what correction? If we adopt that proposed by Le Chatelier, we still find that Mannesmann's results do not agree at all with those of

Charpy and Grenet, as is shown by comparing lines 1 and 4 of Table VII.

§ 87. *Mannesmann's curve does not represent solubility.* Finally, the objection which lies against Charpy and Grenet's results—viz., that they do not at all represent the carbon dissolved in the austenite, because their method of chemical analysis was such that any carbon present as cementite would be included, lies far more damagingly against Mannesmann's, for a simple reason. Any arguments brought up to persuade us that in Charpy and Grenet's experiments the austenite was really saturated with carbon and that no cementite was present, and hence that their results really represent the solubility of carbon in the presence of graphite, would be without force if applied to Mannesmann's results, because his conditions were such that he either might not saturate his austenite with carbon, or, if he did saturate it, then that he would go right on adding carbon in the form of cementite, and not in that of graphite. These conditions were that he cemented wrought-iron rapidly at various unstated temperatures, assumed to include 800°, 900°, and 1,000°, without attempting to start the formation of graphite by raising the temperature intentionally above that at which the cementation took place. Such rapid cementations, while on one hand they may not saturate the austenite, yet on the other hand habitually lead to an abundant formation not of graphite but of cementite, as in the common course of the cementation process exemplified in cases O, P, Q and R of § 17, p. 487. If any fact in this whole field is abundantly and clearly proved it is this. Indeed, my original reason for naming this substance "cementite" was that it contains Rinman's "cement carbon," so-called because it is characteristic of cemented steel. M. Charpy himself has shown that iron may be converted into a mass of pure cementite by thus cementing long enough with potassium cyanide. The very fact that among the products of Mannesmann's experiments were "the most varying grades of white cast-iron with from 2 to 4.76 per cent. of combined carbon" (*amorphem Kohlenstoff*, p. 39, l. 4) shows that his conditions led to the formation of much cementite, for a white cast-iron rich in carbon is necessarily rich in cementite. He made no attempt to distinguish between dissolved and cementite carbon, if indeed he knew that they were distinct things.

§ 38. *Summary of the discussion of the accuracy of the Charpy and Grenet curve  $r, r', r''$ .* There are the following reasons, each sufficient in itself, for rejecting this curve as representing the solubility of carbon in pure austenite in the presence of graphite.

Not  $r, r', r''$ , but  $s, s^3$ , is the curve which the data of Charpy and Grenet indicate.

Neither curve deserves confidence, because of the probably large errors introduced by two and perhaps three unjustified assumptions, two of which tend to make the apparent solubilities greater than the true, while the third tends in the opposite direction, so that the true curve may lie an indeterminate distance on either side of the apparent curves thus formed.

Three reasons, each sufficient in itself, show that Mannesmann's curve does not confirm the curve  $r, r', r''$ .

(1) It is very far from  $r, r', r''$ , even if corrected for his wrong temperature-scale.

(2) It cannot be taken as anything more than a freehand sketch, without pretense to quantitative accuracy.

(3) It includes, along with the dissolved carbon which  $r, r', r''$  is supposed to represent, a quantity of cementite-carbon which almost certainly must have been large.

In my opinion, this Charpy and Grenet curve should be rejected outright as absolutely without any basis whatsoever.

§ 39. *What inferences can be drawn from our present data as to the solubility of graphite in austenite?* In the attempt to answer this question I have condensed in Table I. all the data which seem to bear on it. Before going farther let us recognize that there are four distinct sets of numbers with which we have to do. See § 32, p. 499.

AGr, the percentage of agraphitic or non-graphitic carbon, usually but inaccurately called the total "combined" carbon. This is inaccurate, because in suddenly-cooled metal part of this carbon is not combined, strictly speaking, but dissolved.

DC, the percentage of dissolved carbon.

Cem. C, the percentage of cementite-carbon; and

STn, the solubility at any given temperature.

Now it is STn that we are seeking, but it is only AGr that is ever reported. As to the quantity of Cem. C we are much in the dark. As to the relations between these different num-

bers, so far as I now see all that can be asserted positively is given in the following expressions:

$$(1) \text{AGr} = \text{DC} + \text{Cem. C, hence}$$

$$(2) \text{DC} = \text{or} < \text{AGr}.$$

If, in any given experiment, DC has increased at a given temperature,  $T_n$ , then the final DC cannot be greater than  $ST_n$ , or

$$(3) \text{DC} = \text{or} < ST_n.$$

But if, in such experiment, DC has decreased, then the final DC cannot be less than  $ST_n$ , or

$$(4) \text{DC} = \text{or} > ST_n.$$

(3) and (4) simply express the law that any change in the dissolved carbon-content, DC, must carry it towards equilibrium, *i.e.*, towards  $ST_n$ , but not beyond  $ST_n$ .

We might be tempted to go beyond this and assume that whatever change has taken place in the quantity of cementite in any experiment must be in the direction of greater stability, and therefore must be a decrease, representing a change from cementite into graphite, to be represented thus:

$$(5) \text{Cem. C initial} = \text{or} > \text{Cem. C final.}$$

But the instances of the rapid change of graphite into cementite in § 18 show that this step would be most unsafe.

If we knew DC our task would be comparatively easy; but the attempt to infer DC from the changes in AGr without any positive knowledge as to Cem. C is very difficult.

The chief difficulties in the way of bringing order out of this chaos are,

(A) our uncertainty as to whether silicon does or does not lessen  $ST_n$ ;

(B) The uncertainty as to how much Cem. C is present, and hence as to the amount by which AGr exceeds DC;

(C) The uncertainty as to whether, in any given case, DC equals, or exceeds, or is less than  $ST_n$ .

Those who have published curves of solubility may not have realized the seriousness of these difficulties.

§ 40. *Cases in which AGr, made high by long exposure to a higher temperature,  $T_h$ , decreases on exposure to a lower temperature,  $T_l$ .* Here the probability that at  $T_h$  DC has risen above  $ST_l$  makes it probable, from (4), that DC after holding at  $T_l$  is at least as great if not greater than  $ST_l$ , or  $\text{DC} = \text{or} > ST_l$ .

But, from (2),  $AGr =$  or  $> DC$ . Hence in such cases

(6)  $STl =$  or  $< AGr$ .

In such cases, then, the solubility is at least as small as the least trustworthy value found for  $AGr$ , provided, of course, that the  $AGr$  reported is that which actually existed at  $Tl$ . This may be assumed to be true when the iron is quenched at  $Tl$ , but not when, as in the experiments of Wüist and Schlösser, Table I., lines 6 to 14, the iron is cooled slowly from  $Tl$  down, because in this slow cooling  $DC$  may fall below  $STl$  for the low temperature in question,  $Tl$ , and hence  $AGr$  found after this slow cooling may be less than that at  $Tl$ .

§ 41. *Cases in which  $AGr$ , made low by long exposure to a lower temperature,  $Tl$ , increases on exposure to a much higher temperature,  $Th$ .* After long exposure to a temperature like  $750^\circ$ , which, though relatively low, is yet high enough to give a degree of freedom of molecular movement sufficient to permit any excess of  $DC$  to begin falling out of solution, so that  $DC$  approaches  $STl$ , the probability that  $DC$  then is less than  $STh$  makes it probable, from (3), that after holding at  $Th$   $DC$  will be at most as small if not less than  $STh$ , or

(7)  $DC =$  or  $< STh$ .

If in such case  $Cem. C = 0$ , then  $DC = AGr$ , and hence from (7),

(8)  $STh >$  or  $= AGr$ .

In such cases the solubility is at least as great as the greatest value found for  $AGr$ . But unfortunately we are not sure in any of these cases that  $Cem. C = 0$ . Indeed, it may be large.

If  $Cem. C$  is large, *e.g.*, if  $Cem. C > STh - DC$ , then

(9)  $STh < AGr$ .

For instance, if the solubility was 1.00 per cent., the carbon actually dissolved 0.80 per cent., and the cementite-carbon 0.30 per cent., the total agraphitic carbon would be 1.10 per cent., or greater than the solubility.

By comparing (8) and (9) we see that the solubility in this case may be either greater or less than the agraphitic carbon, or

(10)  $STh >, =$  or  $< AGr$ .

The assumption on which (9) rests, that even after a long exposure to a high temperature, much of the metastable cementite may remain unconverted into the stable graphite, seems to me wholly reasonable. Indeed, carbon which has

once changed into graphite may change back indirectly into cementite, as is shown clearly by Osmond's experiment, case S of § 18, p. 488. The fact that the cooling-curve of this metal was that of a high-carbon steel, with its  $A_r$ , very strongly marked at  $700^\circ$ , shows not only that the originally very small quantity of AGr (0.24 per cent.) had increased very greatly, but further that, on cooling past  $A_r$ , much of that carbon actually changed from DC into Cem. C in the form of pearlite. Benedicks<sup>48</sup> accepts this belief that graphite may thus change into cementite. § 18 gives some additional cases.

§ 42. *To sum these two cases up*, if the iron has been cooled from a much higher to a much lower temperature and then quenched, the solubility is at least as low as the lowest trustworthy value then found for the total agraphitic carbon; but if the iron has been heated from a lower to a much higher temperature and then quenched, the solubility at that higher temperature may be either greater or less than the greatest trustworthy value found for the agraphitic carbon, and by an indeterminate amount. In short, if we call the temperature at which the iron is quenched TQ, and STQ the solubility at TQ, then on quenching after falling temperature

(11)  $STQ =$  or  $<$  AGr;

whereas on quenching after rising temperature

(12)  $STQ >, =, \text{ or } <$  AGr.

Indeed, we may go farther and enunciate the law as follows:

If before quenching DC has been decreasing, then

(11)  $STQ < \text{ or } =$  AGr.

But if DC has been increasing, then

(12)  $STQ >, =, \text{ or } <$  AGr.

In short, for the foregoing reasons, cases like those before us in which the quantity of cementite is unknown, are competent only to give an upper limit for the solubility of carbon; that is to say, only to give a number which the solubility cannot exceed, though it may be less than that number by an indeterminate

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<sup>48</sup> "Hingegen lässt sich ja Cementit aus Ferrite oder Mischkristallen + Graphit auf Umwegen sehr einfach darstellen, wenn nur erhitzt wird, so dass der Graphit in Lösung geht. Beim Abkühlen wird sich die Kohle zunächst als Cementit abscheiden. Durch genügend hohes Erhitzen eines jeden stabilen Fe-C-Systems und genügend schnelles Abkühlen lässt es sich in das metastabile System überführen." C. Benedicks, *Metallurgie*, vol. iii., No. 14, p. 473 (July 22, 1906).

amount. They are in their very nature incompetent as evidences of the lower limit for solubility.

But the matter is even worse than this. Because cementite may re-form on heating even graphitiferous iron, such irons may thus be conglomerates in the second degree, made up of independent conglomerates (A) of austenite and graphite, and (B) of austenite and cementite. Hence, if the solubility in such irons were actually determined, it would not be that here sought, viz., the solubility of carbon in the presence of graphite, but a number somewhere between this and the solubility in the presence of cementite, and therefore presumably greater than the solubility in presence of graphite alone.

To sum this up, the present evidence in its nature can give us only an upper limit for solubility; and even the solubility thus vaguely pointed at is not the solubility sought, viz., that in the presence of graphite, but is probably a greater number somewhere between the solubility sought and the solubility in the presence of cementite.

Here, as usual, the work of the fingers is useless until interpreted by the mind. It is only the raw material out of which the mind must construct the truth.

Nevertheless, let us go on to see what upper limit can be set from the data at hand.

§ 43. *Does the presence of silicon lessen the solubility of carbon?* This question ought, if possible, to be answered before we attempt to determine the solubility. If silicon does not lower STn, then the results reached with irons of different silicon-content can be used to check and verify each other. If it does lower the solubility, then the position of the curve of solubility shifts with the silicon-content. If, finally, we are in doubt whether silicon does or does not lower STn, then this same doubt attaches to the inferences which we reach from a comparison of the results given by irons of different silicon-content.

When the numbers of Table I. are first examined they promise to give an answer to this question, but in view of the considerations which have just been set forth in §§ 39 to 42, that answer proves to be equivocal.

Passing over the general decrease in agraphitic carbon-content with increasing silicon in cases 1 to 5 and 6 to 14 of Table

TABLE VIII.—*Data of Table I. Rearranged.*  
(The designation numbers are those of Table I.)

| No.<br>D | Si.   | Ag.<br>(C.C.)   | Tr.<br>E | Ag.<br>(C.C.) | Tr.<br>E | Ag.<br>(C.C.) | Tr.<br>E   | Ag.<br>(C.C.) | Tr.<br>E     | Ag.<br>(C.C.) | Tr.<br>E     | Ag.<br>(C.C.) | Tr.<br>E |       |
|----------|-------|---|----------|---------------|----------|---------------|------------|---------------|--------------|---------------|--------------|---------------|----------|-------|
| 5        | 2.10  | Charpy and Grenet. On reheating a cast-iron initially containing 3.10 per cent. C. C., and then quenching it, the Ag (C. C.) had fallen to.....                 | 0.54     | 800° 4 hr.    | .....    | 0.88          | 900° 4 hr. | 0.93          | 1,000° 4 hr. | 1.00          | 1,100° 4 hr. | .....         | .....    |       |
| 18 A     | 4.23  | Heyn and Bauer. On reheating a graphitic cast-iron of 4.23 per cent. silicon and quenching it, the Ag (C. C.) fell from between 0.59 and 0.84 per cent. to..... | 0.19     | 800° 1 hr.    | .....    | 0.62          | 900° 1 hr. | 0.53          | 1,000° 1 hr. | 0.56          | 1,050° 1 hr. | .....         | .....    |       |
| 19       | 0.10± | Charpy. On reheating a cast-iron of 0.10± per cent. silicon and quenching it, the Ag (C. C.) changed from 0.41 per cent. to.....                                | 0.31     | 750° to 7 hr. | 6        | 850° to 7 hr. | 6          | 850° to 7 hr. | 0.82         | 900° 2 hr.    | 0.53         | 900° 2 hr.    | .....    | ..... |
| 20       | 0.10± | Charpy. Cast-iron containing 2.82 per cent. Ag (C. C.) initially reheated to 1,150°, cooled slowly to 1,000° and quenched.....                                  | .....    | .....         | .....    | .....         | .....      | .....         | 1.08         | 1,000° 3 hr.  | 1.36         | 1,050° 3 hr.  | .....    | ..... |
| [50]     | 0.10± | Charpy. Cast-iron like No. 20 was cooled from the molten state to 1,000°, held there 3 hours and quenched.....  | .....    | .....         | .....    | .....         | .....      | .....         | 0.92         | 1,000°.....   | .....        | .....         | .....    | ..... |
|          |       |   |          |               |          |               |            |               | 0.95         | 1,000° 3 hr.  | .....        | .....         | .....    | ..... |

No. 5. Charpy and Grenet heated to the temperatures indicated a cast-iron which contained originally

| Per Cent. | Carbon.    | Per Cent. | Silicon.  | Manganese. | Phosphorus. | Sulphur.  |
|-----------|------------|-----------|-----------|------------|-------------|-----------|
| 3.10      | Ag.<br>Gr. | Per Cent. | Per Cent. | Per Cent.  | Per Cent.   | Per Cent. |

| Per Cent. | Carbon.    | Per Cent. | Silicon.  | Manganese. | Phosphorus. | Sulphur.  |
|-----------|------------|-----------|-----------|------------|-------------|-----------|
| 3.30      | Ag.<br>Gr. | Per Cent. | Per Cent. | Per Cent.  | Per Cent.   | Per Cent. |

and then quenched it in cold water.

No. 18 A. Heyn and Bauer, *Stahl und Eisen*, vol. xxvii., No. 44, pp. 1567-9 (Oct. 30, 1907); their iron No. 419. The iron was made by melting together cast-iron and ferrosilicon of the following composition:

|                 |                   |                    |                      |                       |                    |
|-----------------|-------------------|--------------------|----------------------|-----------------------|--------------------|
| Cast-iron, .    | Carbon. Per Cent. | Silicon. Per Cent. | Manganese. Per Cent. | Phosphorus. Per Cent. | Sulphur. Per Cent. |
| Ferrosilicon, . | 2.95              | 0.63               | 0.22                 | 0.09                  | 0.33               |
|                 | 96.               | 96.                | 0.27                 | 0.041                 | 0.108              |

Thus the cast-iron must have contained much sulphur.

No. 19. Charpy, *Revue de Métallurgie*, vol. v., No. 2, Mémoires, p. 77 (Feb., 1908). This case is the same as No. 19 of Table I.

I., because it can readily be explained by catalytic action, I have condensed in Table VIII. certain cases which cannot be so lightly disposed of.

Here the evidence tending to show that silicon does not lessen the solubility is certainly striking. It is that the great difference in silicon-content between case 4 and case 5, and that between case 5 on one hand and cases 20 and 21 on the other, leads to no material difference in agraphitic carbon-content, as shown in the former group by the agraphitic carbon found at 900°, and in the latter group by that found at 1,000°. The evidence of the former group is all the more striking because of the large number of results which agree almost exactly, 3 out of 4 in case 4 and all three in case 5. But on closer examination I brush both these agreements aside as simply two of the many cases in which accidental coincidence obstructs the progress of knowledge. My reason for this apparently rash step is that these coincidences really contradict each other. Thus, following the law that the lowest trustworthy result when AGr is decreasing should be taken as that which least exceeds STn, I take STn for case 5 as follows:

TABLE IX.—*Most Probable Apparent Values for the Solubility of Carbon.*

| Temperature.....          | 700° ..... | 800° ..... | 900° ..... | 1,000° ..... | 1,100° ..... |
|---------------------------|------------|------------|------------|--------------|--------------|
| STn not greater than..... | 0.28 ..... | 0.54 ..... | 0.88 ..... | 0.93 .....   | 1.00 .....   |
| Difference .....          | 0.26 ..... | 0.34 ..... | 0.05 ..... | 0.07 .....   | .....        |

Thus, I assume that STn must be at least as small as 0.54 per cent. for 800°, as 0.93 per cent. for 1,000°, and as 1.00 per cent. for 1,100°. Admitting this, and further admitting that it is extremely probable that STn from 700° to 1,100° is a smooth curve, I hold that ST 900° is extremely probably less than the 0.88 per cent. reported, because this number falls too little short of the number (0.93 per cent.) found for 1,000°. Hence, I hold that the agreement of 6 out of 7 determinations in cases 4 and 5 at 900° is simply an accidental agreement in error. So, too, I hold that the value, 0.93 per cent., found for STn at 1,000° in case 5 is very probably too great, because it falls too little short of the number, 1.00 per cent., found for

1,100°, and because it greatly exceeds the number, 0.53 per cent., found by Heyn and Bauer at 1,000°, in case 18A. In short, these agreements between the agraphitic carbon of cast-irons which differ greatly in silicon cannot be accepted as valid evidence that silicon does not influence the solubility of carbon, because in each of these agreements the reported agraphitic carbon of the high-silicon iron is probably much greater than the dissolved carbon proper.

Further evidence may show that the numbers which I thus reject are right. Nevertheless, my present position seems to me the only logical one, to reject numbers the only value of which lies in their agreement, when they are contradicted by other numbers intrinsically more probable because of the law that, when AGr is decreasing, the STn must be as low as the lowest trustworthy AGr reported.

As between this law on one hand, and an agreement between results which have nothing but that agreement in their favor on the other hand, the former seems to me a firmer basis for probability.

Evidence that silicon does lower the solubility must, unless based on knowledge of the quantity of cementite present, be inconclusive in the very nature of the case. Without that knowledge the evidence would have to be both extensive and harmonious to be convincing. Just as we pass by the evidence of the two important groups, cases 1 to 5 and cases 6 to 14, because in each the decrease of agraphitic carbon-content with increasing silicon can be explained by the assumed catalytic action of that silicon, so may we pass by the very striking results in the high-silicon iron of cases 18 and 18A, in which, though DC was presumably decreasing so that AGr is presumably greater than STn, yet the AGr was only 0.54 and 0.53 per cent. at 1,008° and 1,000° respectively, or but little more than half of the lowest AGr in any lower-silicon iron the AGr of which, at 1,000°, has been preserved by quenching. In the same way the AGr in the high-silicon iron No. 18A falls to 0.19 per cent. at 800°, or only about half as much as the lowest AGr in any lower-silicon iron of which the AGr at 800°, or even at 750°, has been preserved by quenching. In short, an increase in the silicon-content is accompanied by a decrease of about half in the agraphitic carbon-content.

Striking as is the apparent influence of silicon in these cases in lowering the AGr, there is nothing to show whether its action is purely catalytic or whether part at least of its effect is due to its decreasing the solubility. And what is true of this evidence seems to me true of all the rest,<sup>49</sup> including some which, at first sight, seems to show directly that silicon lessens the solubility. The evidence to which these last words refer will be considered in § 44.

§ 44. *Cases in which the lowering of the agraphitic carbon by silicon may really represent nothing but the formation of cementite in graphitiferous iron. Comparison of Cases 17 and 17A with 18 and 18A.* Certain of the cast-irons of cases 17 and 18 which had been cooled slowly to the room-temperature (column 3 of Table I.) were then reheated to known temperatures and

<sup>49</sup> There is one piece of evidence which tends to show that the action of silicon is something more than catalytic, and hence that it really lessens the solubility. This is, that an increase in silicon-content does not seem to lower the AGr so greatly at 700° and 800° as at 1,000° and 1,100°. Now the higher the temperature the less should be the lag, and the less conspicuous, therefore, ought to be the influence of a purely spurring catalytic action in lessening that lag. Hence the apparently greater influence of silicon in lessening DC at 1,000° and 1,100° than at 700° and 800° is more readily explained by its actually decreasing the solubility than by its having a purely catalytic action. Even if this evidence is taken as only a straw to show which way the wind blows, I give it as a straw to which, perhaps, others may later be added with convincing effect.

This greater influence at the higher than at the lower temperatures is shown in the following numbers, taken, as usual, from the lowest results in each group of cases in which DC is presumably decreasing.

TABLE X.—*Silicon Lessens the Agraphitic Carbon more at High than at Low Temperatures.*

| Case.           | Si.   | 700°        | 800°            | 900°        | 1,000°      | 1,100°           |
|-----------------|-------|-------------|-----------------|-------------|-------------|------------------|
|                 |       | AGr. (C.C.) | AGr. (C.C.)     | AGr. (C.C.) | AGr. (C.C.) | AGr. (C.C.)      |
| 3.....          | 0.80  | 0.38        | 0.43            | 0.99        | 1.29        | 1.26             |
| 5.....          | 2.10  | 0.28        | 0.54            | 0.88        | 0.93        | 1.00             |
| Difference..... |       | +0.10       | —0.11<br>(750°) | +0.11       | +0.36       | +0.26            |
| 19.....         | 0.10± | .....       | 0.31            | .....       | .....       | .....            |
| 20.....         | 0.10± | .....       | .....           | .....       | 0.92        | .....            |
| 5.....          | 2.10  | .....       | .....           | .....       | 0.93        | 1.00<br>(1,050°) |
| 18A.....        | 4.23  | .....       | 0.19            | .....       | 0.53        | 0.56             |
| Difference..... |       | .....       | +0.12           | .....       | +0.40       | +0.44            |

The designation numbers of these cases are the same as those used in Table I.

quenched, so as to preserve the condition then reached. After the original slow cooling to the room-temperature the AGr was naturally much less in the high- than in the low-silicon iron. But the important point is that, whereas in the reheatings to 800° and 900° the AGr of the high-silicon iron seems<sup>50</sup> to have decreased, and hence though low yet to be greater than the solubility for 800° and 900°, yet the AGr of the lower-silicon iron seems<sup>50</sup> to have increased, which (if we ignore variations in Cem. C) suggests that though high it is less than the solubility for 800° and 900°.

This seems to argue that the solubility is less for the high- than for the low-silicon iron, or, in short, that silicon lowers the solubility. But this increase of AGr in the low-silicon iron may have been due wholly to a large increase in cementite, and there may really have been a decrease in DC masked by this increase in Cem. C. If so, this case would no longer suggest that silicon lowers the solubility.

§ 45. *Formation of cementite from graphite.* That cementite may well form under these conditions is indicated by a comparison of cases 19 and 20 of Table I. The fact that the AGr of case 20 fell at 1,000° from 2.82 to 0.92 shows that ST 1,000° must be at least as low as 0.92 per cent. With this number, 0.92 per cent., in mind, the much larger numbers, 1.08 at 1,000° and 1.36 at 1,050°, to which the AGr of No. 19 increased from 0.41 per cent., cannot be regarded as representing DC. STn cannot be thought to have jumped from 0.92 per cent. at 1,000° to 1.36 per cent. at 1,050°. The silicon and other elements seem to have been alike in these cases. Hence we infer that the excess of AGr in case 19 must be due to the formation of much, indeed, at 1,050° of very much, cementite.

Thus we see that our inability to infer from the comparison of cases 17, 17A, 18, and 18A whether silicon does or does not lower the solubility is due to our uncertainty as to the quantity of cementite present. If we knew that the increase of AGr in these low-silicon irons was not due to a large increase in cementite, then we should have strong reason to think that

<sup>50</sup> I say "seems to" because the discrepancies between the different analyses which Heyn and Bauer with a proper frankness give in detail, may raise a doubt in some minds whether the increase and decrease of which I here speak really took place.

silicon does lower the solubility. Thus it seems to me that the first thing needed to aid our study of the effect of silicon is quantitative determination, or at least micrographic estimation, of the cementite present, a labor which I commend to our metallographers. I recognize the difficulties which the quenched condition of the specimens may cause in this estimation.

§ 46. *The position of the curve of solubility as shown by the present data.* What assumption shall we make as regards the effect of silicon on the solubility? Let us assume that silicon does not lower the solubility, but in examining the results of our study let us consider which of them rest on this assumption and which do not. To the latter class belong the results reached with irons nearly free from silicon. Indeed, it seems to me that this is all that can be done, because our data are too scanty to permit us to make a series of inferences, a first as to silicon-less irons, a second as to those with a moderate quantity of silicon, a third for those with somewhat more, and so on.

§ 47. *Solubility at 500°.* Case 14 of Table I. indicates that the solubility falls to zero somewhere above 500°. Here cast-iron containing initially 0.25 per cent. of graphite and 2.71 per cent. of agraphitic carbon, though it underwent no change on staying for 3 hr. at 500°, had the whole of its combined carbon changed to graphite when held for 3 hr. at 600° and cooled slowly. From the fact that no combined carbon changed to graphite at 500°, in spite of the initial presence of 0.25 per cent. of graphite to act as a nucleus to start graphitization, I infer that it is probable that graphitization will not occur at temperatures as low as 500°. Hence I infer that the complete change of the 2.71 per cent. of combined carbon into graphite, which occurred in the heating to 600° and cooling thence, must have occurred before the temperature had sunk as low as 500°, and hence that the solubility must have sunk to zero at some point higher than 500°.

§ 48. *Indications that the solubility may be very low at a relatively high temperature.* There are two facts which support the belief that the solubility falls nearly or quite to zero at a temperature at least moderately high. Of these, the first is the familiar one that many commercial cast-irons are practically free from agraphitic carbon, even if their cooling is not very

slow.<sup>61</sup> The cooling of the cast-iron in the sand mold in the casting-house of the iron blast-furnace is rarely extremely slow. In general, the pigs are broken up and thrown out of the sand soon after they have solidified, for the important practical reason that they can then be broken off easily from the sow or runner. Thus disturbed and exposed to the air, even to the cold air of winter, they are often nearly free from agaphitic (combined) carbon. This implies not only that STn has fallen nearly or quite to zero, but further that the temperature at which it has thus fallen must be high enough to enable the dissolved carbon actually to obey this low solubility and to fall thus nearly or quite completely out of solution.

The second of these two facts is that, in many micrographs of cast-iron, either large regions or the whole of the area shown consists of nothing but pure graphite and apparently pure ferrite. To me this indicates, first, that at some temperature or other, Ty, the solubility of the carbon in the iron has fallen to zero; second, that this temperature, Ty, is a rather high one, probably well above 700°, for an extremely simple reason. The actual precipitation of the carbon from the austenite as graphite in cooling must have extended at least down to Ty, and may, through lag, have extended below Ty. Now, the fact that the graphite which has thus separated has coalesced completely into large islands, leaving no visible uncoalesced islets of graphite, indicates that Ty must be high enough to give to the matrix of austenite such mobility as will permit the initially scattered islets of graphite thus to coalesce completely into large islands with considerable rapidity. That the temperature which does this is above 700° I infer from the facts that the sheetlets

<sup>61</sup> I find the following cases, which seem especially deserving of confidence :

| Combined (agaphitic)<br>Carbon in Cast-Iron.   |
|--|
| Percy, <i>Metallurgy, Iron and Steel</i> , p. 536, . . . . . 0.00 (Abel).  |
| Percy, <i>Metallurgy, Iron and Steel</i> , p. 547, . . . . . 0.04 (E. Riley).  |
| Lebedur, <i>Eisenhüttenkunde</i> , fifth edition, vol. ii., pp. 20, 21<br>(1906), . . . . . . . . . . . 0.00 ferrosilicon. |
| 0.00 ferrosilicon.   |
| 0.15 No. 3 pig-iron.   |
| 0.13 No. 3 pig-iron.   |
| 0.17 No. 3 pig-iron.   |

Besides these, which seem to be commercial cast-irons, the very many commercial published analyses with but a very small quantity of combined carbon deserve a certain weight.

of cementite and ferrite, interstratified in steel as pearlite, do not rapidly coalesce at  $700^{\circ}$ , as is shown by the fact that well-formed pearlite, showing no sign of such coalescence, remains after even rather slow cooling from  $700^{\circ}$  down; indeed, after a cooling probably much slower than that which, in the casting-house of the iron blast-furnace, seems to suffice to permit this complete coalescence of the islets of graphite separated above  $T_y$ .

We may therefore adopt provisionally, as a working hypothesis, that the solubility of carbon in iron in presence of graphite falls to zero at some temperature certainly not below  $500^{\circ}$ , probably not below  $700^{\circ}$ .

Of great importance in this connection is the observation of Goerens and Gutowsky that, in a hypo-eutectic cast-iron which they quenched at  $1,135^{\circ}$ , the beginning of the eutectic freezing, the primaustenoid pine-trees are crossed with needles of cementite where they adjoin the cementite-austenite eutectic, but are free from them (and also it appears from graphite) where they adjoin the graphite-austenite eutectic. The freedom from cementite needles argues that these latter primaustenoid masses obeyed the graphite-austenite diagram in their very birth. But if this is admitted, then their freedom from graphite argues that, as these pine-trees grew in cooling through region 2 of Fig. 1, p. 463, no graphite was precipitated, because if any had been, it should be visible in these pine-trees. Next, if no visible quantity of graphite is precipitated, is not that an indication that there is no considerable decrease in the solubility of carbon in presence of graphite in cooling through region 2? But, if the solubility were considerable, then there ought to be a considerable decrease of it and a considerable precipitation of graphite. The absence of this precipitation, then, is a suggestion that, even at this high temperature, the solubility of carbon in presence of graphite is small.

Beyond inferring that the solubility of carbon in presence of graphite is probably less than others have believed, we may here begin to suspect that it is exceedingly small, or perhaps even *nil*, even at high temperatures. This observation of Goerens and Gutowsky gives us a hint in that direction. The absence of fine particles of graphite from some graphitic irons just noted gives us another such hint. On the other hand, our

present theory implies that the first step in the now well-established change of graphite into cementite is the dissolving of that graphite in the austenite, to be followed by reprecipitation of the carbon as cementite. But the rapidity with which this change occurs certainly suggests that this dissolving of graphite must go on rapidly, and hence that the solubility of graphite is considerable. Or is our theory wrong?

§ 49. *Solubility at 700°.* In § 43 we inferred from case 5 of Table I. that the solubility at 700° ought to be 0.28 per cent. or less. Applying expression (6) to case 19 of Table I., we find a number very near to this, 0.31 per cent. Therefore, we may infer provisionally that the solubility is not greater than 0.28, even in case the silicon-content is low. The still lower number, 0.17 in case 14, should be rejected, because it may have been reached during the slow cooling below 700°.

§ 50. *Solubility at 800°.* On the principle that the lowest trustworthy result must be taken as that which is least in excess of the true solubility, the number 0.54 per cent., based in § 43 on case 5, should be replaced by the still lower number, 0.19 per cent., based on case 18A. This is, indeed, a very high-silicon iron, but the influence of its silicon is likely to have been offset in large part by its high sulphur-content. As in case of 700°, so here the still lower number, 0.12 per cent. of case 14, must be rejected, because of the opportunity for the dissolved carbon-content to decrease below ST 800° in the slow cooling from 800° down.

§ 51. *Solubility at 900°.* The very close agreement between six of the seven results in cases 4 and 5 at first sight raises a certain presumption that they represent truly the solubility at 900°. How, it may be asked, is it possible that these six results should all be out of equilibrium, either through containing dissolved carbon in excess of the true solubility or through containing cementite not yet changed into graphite, and yet should agree so closely? But we have already seen that, harmonious as these results are, they are to be rejected because contradicted by the more trustworthy results of this same case 5, 0.54 per cent. for 800° and 0.93 per cent. for 1,000°. They thus appear to be too high even for this relatively low-silicon iron. So, too, we must reject the other semi-direct datum as to ST 900°—viz., the falling of AGr to 0.62 per cent. in the high-silicon iron

No. 18A, because still lower AGr is reached at 1,000° in case 18A, as the next section shows. Hence, because ST 900° is not indicated by any trustworthy results at 900°, it must be reached by interpolation between ST 800° and ST 1,000°.

§ 52. *Solubility at 1,000°.* Among the very low-silicon irons there seems, at first sight, to be a cogently close agreement between the falling AGr of cases 20 and 21, 0.92 and 0.95 per cent., and the rising AGr of case 19, 1.08 per cent. But, as already explained, I incline to reject all of these summarily, the 1.08 per cent. because it probably represents much Cem. C, just as the AGr of this same case at 1,050°, 1.36 per cent., certainly represents much Cem. C, and the 0.92 and 0.95 per cent. of cases 20 and 21, because there is every reason to believe that, with this extremely low silicon, about 0.10 per cent., the lag is far too great to permit AGr to approach STn closely in the short time here given, so that they, too, are probably much greater than STn. In the 4-hr. exposures to 1,000° of cases 2 and 3, with much more silicon, the AGr evidently remained very much greater than STn, because much greater than the AGr of cases 20 and 21. The intrinsic improbability that AGr has closely approached STn in the short exposures of cases 20 and 21 is far too great to be set aside because of the agreement between these and the 1.08 per cent. reached in case 19, especially in view of the fact that the difference is wrong in sign. The falling AGr of cases 20 and 21 should remain greater than STn, the rising one of case 19 should remain less than STn, and thus, *a fortiori*, less than those of 20 and 21, whereas it is actually 0.16 per cent. greater than that of case 20. These results, then, would carry no great weight even on the theory that silicon does not lower the solubility of carbon, STn. All that can be said confidently for them is that, among the low-silicon results reached at 1,000°, these are the ones least in excess of ST 1,000°.

In short, on the theory that silicon does lower the solubility these results, as applicable to low-silicon iron, are questionable, because of too short exposure to 1,000°; on the other theory, that silicon does not lower the solubility, they are, of course, flatly contradicted by the much lower AGr reached, 0.54 in case 18, 0.53 in case 18A.

To sum this up, the numbers we have here selected as the

least in excess of STn, *i.e.*, as giving an upper limit, at an indeterminate distance below which STn must lie, are those of the first four lines of Table XI., the last line of which gives for comparison the numbers put forward by some previous writers in the incorrect belief that they were supported by the results of Charpy and Grenet and of Mannesmann. Whether for high or for low silicon, these latter numbers are evidently above the true upper limit of solubility, and they may be very much above the solubility itself.

TABLE XI.—*Provisional Upper Limits for the Solubility of Carbon in Austenite in the Presence of Graphite.*

(The true solubility should not be greater than these numbers and may be less than them by an indeterminate amount.)

| Temperature .....                         | 500° to 600°. | 700°.                      | 800°.        | 900°.        | 1,000°.      |              |
|---|---------------|----------------------------|--------------|--------------|--------------|--------------|
| Silicon-Content.                          | Case No.      | Upper Limit of Solubility. |              |              |              |              |
|   |               | C. Per Cent.               | C. Per Cent. | C. Per Cent. | C. Per Cent. | C. Per Cent. |
| 0.10±                                     | 20            | .....                      | .....        | .....        | .....        | 0.92         |
| 2.10                                      | 5             | .....                      | 0.28         | 0.54         | .....        | .....        |
| 3.15                                      | 14            | 0                          | 0.?          | .....        | .....        | .....        |
| 4.23                                      | 18A           | .....                      | .....        | 0.19         | .....        | .....        |
| Numbers Offered by Some Previous Writers. |               |                            |              |              |              |              |
| .....                                     | .....         | .....                      | 0.70         | .....        | 0.90         | 1.30         |

These numbers must be taken as only very rough approximations to the truth, reached by means of assumptions which are open to question. Indeed, I doubt whether they are worth intrinsically what it has cost to reach them. My purpose in seeking them has been to show how great caution should be used in attempting to determine the solubility.

§ 53. *The formation of cementite in reheating graphitiferous iron.* § 45 showed that the high AGr of case 19 at 1,050° was probably due to the formation of much cementite in an iron already very graphitic, *i.e.*, to a change from graphite into cementite. This change may well have been an indirect one, the graphite first dissolving in the austenite and then re-crystallizing out as cementite. The same thing seems to have happened when

Royston (case 27) on reheating black-heart malleable cast-iron, of which the carbon was apparently wholly graphitic, made 0.85 per cent. of the carbon recombine at  $720^{\circ}$  and 1.50 per cent. at  $1,030^{\circ}$ . Both these numbers are very much above the upper limit for STn, shown in Table XI., and *a fortiori* greater than the probable DC. Their excess over DC seems to represent cementite formed from the original graphite.

§ 54. *Influence of silicon on the eutectic carbon-content.* Heyn and Bauer<sup>52</sup> make the interesting observation that cast-iron containing 4.16 per cent. of silicon and 3.12 per cent. of carbon is practically of eutectic composition, as is shown by the fact that the retardation in freezing is confined within very narrow temperature-limits. This goes to show that the presence of this 4.16 per cent. of silicon has shifted the eutectic ratio from its normal position in silicon-less iron, 4.30 per cent., to the neighborhood of 3.12 per cent., and to confirm my inference to the same effect, from the fact that, if the pig-iron is rich in silicon, then much kish is found blowing about the mixers in which the iron is stored, but not if the silicon is low.<sup>53</sup> This kish is probably the primary graphite, which rises to the surface by gravity, and so, because of its lightness and of the breadth of its flakes, is readily thrown out of the molten metal and into the air by any small quantity of escaping gas.

§ 55. *Meaning of the retardation at  $1,050^{\circ}$ .* Following Roozeboom, Dr. Benedicks explains the retardation at  $1,050^{\circ}$  by supposing that it represents the precipitation of cementite in the interior of the eutectic austenite, as, by fall of temperature, this becomes sufficiently supersaturated with cementite to induce this precipitation in the absence of nuclei of cementite.<sup>54</sup> At the surface of the masses of eutectic austenite, the bands of eutectic cementite, acting as nuclei, might suffice to cause the cementite to precipitate out of the eutectic austenite nearly as fast as the solubility of carbon in it decreases, or at least to prevent great lag; but in the interior of these masses, where such nucleus-action is lacking, a considerable degree of supersaturation may occur, and, once the excess of cementite then

<sup>52</sup> *Stahl und Eisen*, vol. xxvii., No. 44, p. 1566 (Oct. 30, 1907).

<sup>53</sup> *Iron, Steel, and Other Alloys*, 2d edition, p. 210 (1906).

<sup>54</sup> *Metallurgie*, vol. iii., No. 13, p. 434 (July 8, 1906).

begins to separate, its separation may be so rapid as to retard the cooling. This temperature, 1,050°, then would in a way correspond to a change from a metastable to a labile condition, from a condition in which an overdue transformation occurs only in case it is stimulated by the presence of nuclei of the stable substance to one in which it occurs even in the absence of such nuclei.<sup>55</sup>

However well this may explain the occurrence of this 1,050° retardation in cooling from the molten state, it does not seem to explain easily its occurrence, which Dr. Offerhaus and I have repeatedly noticed, in the cooling of pieces reheated to well below incipient fusion. In these pieces it is hard to believe that there should not remain enough undecomposed cementite within the austenite to give the nucleus action needed to start the re-precipitation of cementite as the solvent power of the austenite decreases.

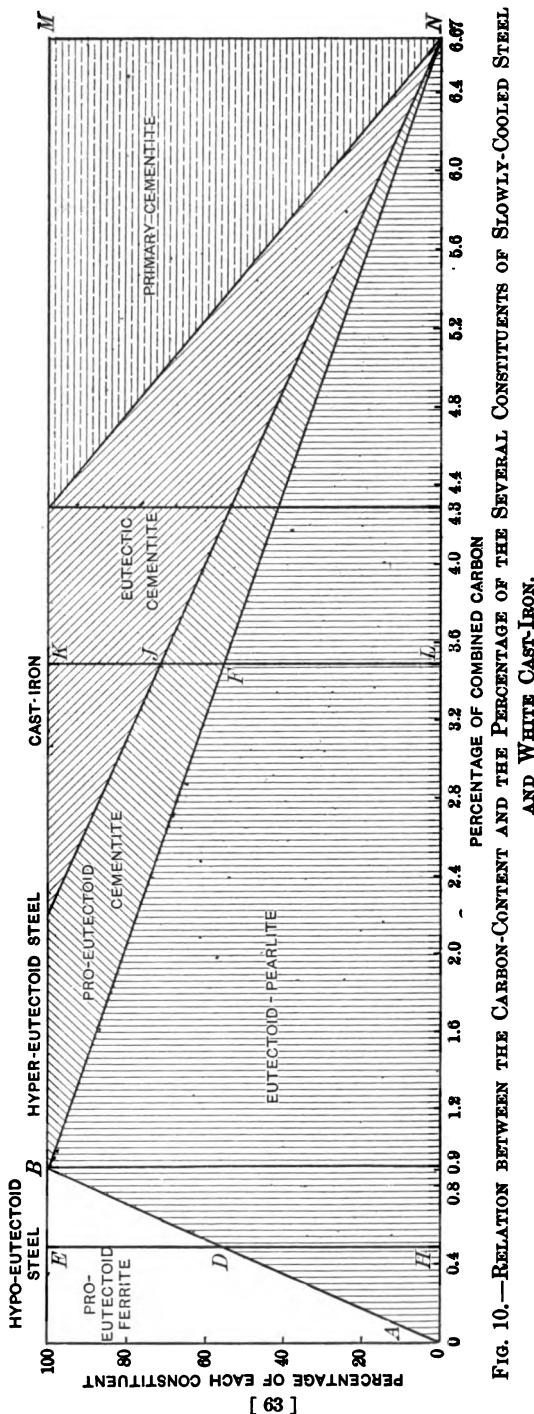
#### APPENDIX.

*Diagram indicating the relation between the carbon-content and the proportion of each of the constituents present, Fig. 10.* This diagram is on the general plan so well used by Prof. Sauveur. Abscissæ indicate the carbon-content, the ordinates of the lines *AB* and *BN* indicate the quantity of pearlite, assuming that it retains the whole of its initial mass, and that none of either of its constituents, ferrite or cementite, has coalesced, and so ceased to retain the original pearlitic structure. The proportion of pro-eutectoid ferrite is given (as in Prof. Sauveur's original diagram) by the intercept *ED*, the primary cementite by *MN*, the eutectic cementite by *KJ*, and the pro-eutectoid cementite by *JF*.

The general procedure in calculating the quantities of primary, eutectic, pro-eutectoid, and eutectoid cementite is as follows:

*Case 1, carbon 4.30 per cent.* The whole mass at 1,130° consists of a eutectic of austenite and cementite. The austenite contains 2.20 per cent. of carbon, the cementite 6.67 per cent. of carbon. The carbon in the *x* per cent. of austenite plus the

<sup>55</sup> See interesting determinations of the passage from the metastable to the labile state in many liquids, water included, Miers and Isaac, *Transactions of the Chemical Society*, vol. lxxxix., p. 413 (1906), and *Chemical News*, vol. xciv., No. 2439, p. 89 (Aug. 24, 1906); also Isaac, *Transactions of the Chemical Society*, vol. xciii., p. 384 (1908).



$y$  per cent. of cementite is, by assumption, 4.30 per cent. of the whole mass.

Let  $x$  = the percentage of the austenite in the whole mass at  $1,130^\circ$ .

Let  $y$  = the percentage of the cementite in the whole mass at  $1,130^\circ$ .

$$(1) 0.022 x + 0.0667 y = 4.30.$$

$$(2) x + y = 100.$$

Solve for  $y$ , the eutectic cementite, which persists unaltered in the cold.

*Case 2, carbon 4.50 per cent.* At  $1,130^\circ$  the mass consists of the eutectic of austenite of 2.20 per cent. carbon and cementite of 6.67 per cent. carbon, plus the primary cementite, also of 6.67 per cent. carbon.

Let  $x$  = the percentage of the eutectic austenite in the whole mass at  $1,130^\circ$ .

Let  $y$  = the percentage of the eutectic cementite in the whole mass at  $1,130^\circ$ .

Let  $z$  = the percentage of the primary cementite in the whole mass at  $1,130^\circ$ .

The carbon in the  $x$  per cent. of 2.2 per cent. austenite plus that in the  $y$  and  $z$  per cent. of eutectic and primary cementite, by assumption, is 4.5 per cent. of the whole mass.

$$(3) 0.022 x + 0.0667 (y + z) = 4.50.$$

The ratio  $x : y$  is here the same as in case 1; hence,

$$(4) x : y = 53 : 47.$$

$$(5) x + y + z = 100.$$

Solve for  $x$ ,  $y$ , and  $z$ .

In cooling through region 7 the primary and the eutectic cementite persist unchanged, but the eutectic austenite, initially of 2.20 per cent. of carbon, is gradually impoverished in carbon by giving birth to the pro-eutectoid cementite, until at  $Ar_1$ , it becomes hardenite of 0.90 per cent. of carbon.

Let  $u$  = the hardenite present at  $Ar_1$ , and

Let  $v$  = the pro-eutectoid cementite there present.

The  $0.022 x$  carbon which at  $1,130^\circ$  was present in the austenite will now be distributed between the hardenite and the pro-eutectoid cementite. Hence,

$$(6) 0.009 u + 0.0667 v = 0.022 x.$$

$$(7) u + v = x.$$

Solve for  $u$  and  $v$ .

## NOTES TO TABLE I.

Nos. 1 to 5. Charpy and Grenet, *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, vol. cii., p. 399 (1<sup>er</sup> semestre, 1902). Five cast-irons, of the composition given below, were first melted and granulated in cold water, after which they contained no appreciable proportion of graphite, except No. 5, which had 0.20 per cent. After exposure to the temperatures indicated they were quenched in cold water.

*a* In these cases the metal was cooled at the rate of 50° per hr. from 1,170° to 900°, and then allowed to cool completely over night. The next day the specimens were reheated to 900°, and then again cooled at the rate of 50° per hr. to the temperatures here given, held there for 2 hr., and then quenched in cold water.

*b* In these cases the cast-iron was heated directly to the temperature given in this table, and after staying there was quenched in cold water.

*c* In these cases the metal was first raised to between 1,100° and 1,170°, then cooled slowly to the temperatures given in this table, and after staying there for the time indicated was quenched in cold water.

*Chemical Composition of Irons, Nos. 1 to 5.*

|                | Carbon.<br>Per Cent.              | Manganese.<br>Per Cent. | Sulphur.<br>Per Cent. | Phosphorus.<br>Per Cent. |
|----------------|-----------------------------------|-------------------------|-----------------------|--------------------------|
| No. 1, . . . . | 3.60                              | 0.03                    | 0.01                  | traces                   |
| No. 2, . . . . | 3.40                              | traces                  | 0.02                  | 0.02                     |
| No. 3, . . . . | 3.25                              | traces                  | 0.02                  | 0.03                     |
| No. 4, . . . . | 3.20                              | 0.12                    | 0.01                  | 0.01                     |
| No. 5, . . . . | 3.30 { C. C., 3.10 }<br>Gr., 0.20 | 0.12                    | 0.02                  | 0.01                     |

Nos. 6 to 14. Wüst and Schlösser, *Stahl und Eisen*, vol. xxiv., No. 19, pp. 1120-3 (Oct. 1, 1904).

No. 16. Benedicks, *Metallurgie*, vol. iii., No. 13, p. 435, bottom (July 8, 1906).

Nos. 17 and 18. Heyn and Bauer, *Stahl und Eisen*, vol. xxvii., No. 44, pp. 1565-71 (Oct. 30, 1907); No. 45, pp. 1621-5 (Nov. 6, 1907). They melted lots of 400 g. each of cast-iron, made by mixing together white cast-iron and ferrosilicon. The composition of these, and of the resultant cast-irons, was as follows:

|                              | Carbon.               |                     |                        |                     | Mn.<br>Per<br>Cent. | P.<br>Per<br>Cent. | S.<br>Per<br>Cent. | Fe.<br>Per<br>Cent. |
|------------------------------|-----------------------|---------------------|------------------------|---------------------|---------------------|--------------------|--------------------|---------------------|
|                              | C. C.<br>Per<br>Cent. | Gr.<br>Per<br>Cent. | Total.<br>Per<br>Cent. | Si.<br>Per<br>Cent. |                     |                    |                    |                     |
| Initial white iron.....      | 2.88                  | 0.07                | 2.95                   | 0.63                | 0.22                | 0.09               | 0.33               | .....               |
| Initial ferrosilicon.....    |                       |                     |                        | 96.                 | 0.27                | 0.041              | 0.108              | 3.50                |
| Resultant cast-iron, No. 17: |                       |                     |                        |                     |                     |                    |                    |                     |
| Maximum.....                 |                       |                     | 3.33                   | 1.72                |                     |                    |                    | .....               |
| Minimum.....                 |                       |                     | 3.05                   | 1.20                |                     |                    |                    | .....               |
| Average.....                 |                       |                     | 3.19                   | 1.47                |                     |                    |                    | .....               |
| Resultant cast-iron, No. 18: |                       |                     |                        |                     |                     |                    |                    |                     |
| Maximum.....                 |                       |                     | 3.14                   | 4.27                |                     |                    |                    | .....               |
| Minimum.....                 |                       |                     | 2.59                   | 2.90                |                     |                    |                    | .....               |
| Average.....                 |                       |                     | 2.93                   | 3.89                |                     |                    |                    | .....               |

The sulphur-content was regrettably high, so high, indeed, that the results are not closely comparable with those of other experimenters who have treated cast-iron of a more normal composition. Each lot of cast-iron was melted in a

TABLE I.—*Graphitic (Total Combined) Carbon of Cast-Iron After Long Exposure to Certain High Temperatures.*

| No. | Sili-<br>con<br>Con-<br>tent<br>Per cent.  | Room <sup>o</sup> | 600 <sup>o</sup> | 700 <sup>o</sup> | 800 <sup>o</sup> | 900 <sup>o</sup> | 1,000 <sup>o</sup> | 1,050 <sup>o</sup> | 1,080 <sup>o</sup> | 1,100 <sup>o</sup> | 1,150 <sup>o</sup> | 1,170 <sup>o</sup> | 1,200 <sup>o</sup> |
|-----|--|-------------------|------------------|------------------|------------------|------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|     |  |                   |                  |                  |                  |                  |                    |                    |                    |                    |                    |                    |                    |
| 1   | 0.07   | 0.27              | 0.43a            | 2                | 1.31a            | 2                | 1.74c              | 2                  | 1.74c              | 2                  | 1.74c              | 2                  | 1.74c              |
| 2   | 0.20   | 0.38a             | 2                | 3.19             | 1.97             | 1                | 2.94               | 1                  | 2.41               | 1                  | 1.93c              | 4                  | 1.48c              |
| 3   | 0.80   | 0.38              | 4                | 0.46a            | 2                | 2.40             | 0.99c              | 2                  | 1.58c              | 2                  | 1.26               | 4                  | 1.69b              |
| 4   | 1.25   | 0.31              | 4                | 3.13             | 3.07             | 4                | 1.14               | 4                  | 1.29               | 4                  | 1.02               | 4                  | —                  |
| 5   | 2.10   | 0.47±             | 6                | 1.19             | 1.90             | 1                | 0.78               | 1                  | 0.88               | 1                  | 0.90               | 4                  | 1.00               |
| 6   | 0.05   | 1.21              | 0.28             | 4                | 0.14             | 4                | 0.90               | 4                  | —                  | —                  | —                  | —                  | 1.43               |
| 7   | 0.078  | 3.58              | —                | —                | —                | —                | 1.98               | 3                  | 3.47               | 3                  | —                  | —                  | 3                  |
| 8   | 0.13   | 4.36              | —                | —                | —                | —                | 3.50               | 3                  | 3.93               | 3                  | —                  | —                  | 3                  |
| 9   | 0.26   | 3.29              | —                | —                | —                | —                | 4.24               | 3                  | 3.02               | 3                  | 2.77               | 3                  | 2.70               |
| 10  | 0.55   | 3.06              | —                | —                | —                | —                | 3.27               | 3                  | 3.02               | 3                  | 0.69               | 3                  | 1.86               |
| 11  | 0.81   | 2.70              | —                | —                | —                | —                | 2.47               | 3                  | 1.98               | 3                  | 0.49               | 3                  | 0.49               |
| 12  | 1.20   | 2.44              | —                | —                | —                | —                | 3.07               | 3                  | 0.70               | 3                  | 0.55               | 3                  | 0.55               |
| 13  | 2.12   | 2.21              | —                | —                | —                | —                | 2.16               | 3                  | 0.62               | 3                  | 0.87               | 3                  | 0.87               |
| 14  | 3.15   | 2.71              | 3.00             | 1.67             | 3                | 0.34             | 3                  | 0.32               | 3                  | 0.35               | 3                  | 0.14               | 3                  |
| 15  | Benedict's solu-<br>bility represented<br>by r, r' and r''   |                   |                  |                  |                  |                  |                    |                    |                    |                    |                    |                    |                    |
| 16  | by r, r' and r''   |                   |                  |                  |                  |                  |                    |                    |                    |                    |                    |                    |                    |
| 17  | A. Combined + Dissolved Carbon left after a Slow Cooling to these several temperatures, interrupted by Quenching at these temperatures.  |                   |                  |                  |                  |                  |                    |                    |                    |                    |                    |                    |                    |
|     | 1.20   | 1.25              | 1.00             | 1.29             | 1.00             | 1.00             | 1.00               | 1.00               | 1.057 <sup>o</sup> | 1.79               | 1.087 <sup>o</sup> | 1.159 <sup>o</sup> | 1.380 <sup>o</sup> |
|     | 1.72   | 1.82              | 1.00             | 1.29             | 1.00             | 1.00             | 1.00               | 1.00               | 1.085 <sup>o</sup> | 1.64               | 1.085 <sup>o</sup> | 1.290 <sup>o</sup> | 1.260 <sup>o</sup> |
|     | B. On Reheating Slowly Cooled pieces of No. 17 to these several temperatures holding for 1/2 hour, and then Quenching, the Graphitic<br>Combined Carbon increased from between 1.5 and 1.51 to |                   |                  |                  |                  |                  |                    |                    |                    |                    |                    |                    |                    |
|     | 1.46   | 1.50              | 1.54             | 1.51             | 1.48             | 1.43             | 1.43               | 1.43               | 1.43               | 1.43               | 1.43               | 1.43               | 1.43               |
|     | Heintz and<br>Pauer.....   |                   |                  |                  |                  |                  |                    |                    |                    |                    |                    |                    |                    |
|     | 1.46   | 1.50              | 1.54             | 1.51             | 1.48             | 1.43             | 1.43               | 1.43               | 1.43               | 1.43               | 1.43               | 1.43               | 1.43               |



graphite crucible under a layer of charcoal, and then allowed to cool slowly in the furnace itself, either to the room-temperature, or to a certain specified temperature, QT, on reaching which the iron was quenched in water, so as to catch as nearly as practicable the condition reached in the slow cooling. The rate of cooling seems to have been about as follows:

|                |           |           |         |         |         |
|----------------|-----------|-----------|---------|---------|---------|
| From 1,200°    | 1,100° to | 1,000° to | 900° to | 800° to | 700° to |
| to 1,100°.     | 1,000°.   | 900°.     | 800°.   | 700°.   | 600°.   |
| Minutes, est., | 6         | 9         | 12      | 15      | 18      |

Certain of the slowly-cooled pieces were then reheated to the temperatures given under 17A and 18A, and then held there for either 0.5 hr. or 2 hr., and then quenched in water.

No. 19. Charpy, *Revue de Métallurgie*, vol. v., No. 2, Mémoires, p. 77 (Feb., 1908). Swedish wrought-iron was cemented and melted in a crucible with an excess of wood-charcoal, and allowed to cool slowly in the crucible, when it contained 3.34 per cent. of graphite and 0.41 per cent. of combined carbon, together with "about 0.10 per cent. of silicon and of manganese, and traces of sulphur and phosphorus." Pieces of this metal 4 cm. cube were then held at the temperatures stated in the table for from 6 to 7 hr. in the 750° and 850° heatings, and 3 hr. in the others, then quenched in water, and reheated to 500° to soften them enough to be cut. 2 mm. were then cut off the faces of each cube. Then filings were taken for analysis.

No. 20. *Idem*. He proceeded as in No. 19, except that the molten metal was cast in a metallic mold, when it contained 2.82 per cent. of combined carbon and no graphite. It was then reheated to 1,150°, doubtless to start the formation of graphite, then cooled very slowly to 1,000° and quenched. After removing the oxidized outside the remainder contained 1.82 per cent. of graphite and 0.92 per cent. of combined carbon.

No. 21. *Idem*. He proceeded in the same way, except that the crucible containing the molten cast-iron was set in a furnace at 1,000°, so that the iron passed directly but very slowly to 1,000°. After staying at 1000° for 3 hr. it was quenched in cold water, when it contained 2.15 per cent. of graphite and 0.95 per cent. of combined carbon.

Here and elsewhere he reports the combined carbon as "dissolved carbon," but it seems clear that under this he includes both the dissolved and the cementite carbon.

No. 22. Royston, case B, § 16, p. 483; *Journal of the Iron and Steel Institute*, vol. li. (1897, No. I.), p. 166.

No. 23. Charpy, case H, § 16, p. 484; *Revue de Métallurgie*, vol. v., No. 2, Mémoires, p. 78 (Feb., 1908). Iron was cemented in wood-charcoal at 1,000°. The length of time is not given, and there is no indication that the metal was quenched instead of being cooled slowly. I infer that it probably was not quenched, from the fact that in many of the experiments described in the same paper he specifically asserts that the metal was quenched, and that in the experiments which he groups together with this No. 23 he omits all reference to the rate of cooling. Hence I have marked it SC (slowly cooled).

The combined carbon-content may be above the true solubility at 1,000°, because much of that carbon may have existed as cementite, as is the case in most cementations. On the other hand, it is conceivable that the combined carbon-content may be below the true solubility, because, if it should have so happened that, at 1,000°, all the cementite had been broken up and its carbon changed into graphite and dissolved carbon, and if this dissolved carbon had been just that which saturated the austenite at 1,000°, then in cooling slowly from 1,000° down, part of this

dissolved carbon would naturally have separated out as graphite because of the decreasing solubility of carbon with falling temperature. Hence the case offers no strong evidence.

No. 24. Charpy, *Comptes Rendus*, vol. cxxxvi., No. 17, p. 1002 (Apr. 27, 1903), and *Iron and Steel Magazine*, vol. viii., No. 4, p. 306 (Oct., 1904). Steel filings containing 2 per cent. of carbon were heated to 1,000° for 36 hr. in pure carbonic oxide, after which they contained 9.27 per cent. of total carbon and 1.00 per cent. of combined carbon. It is probable that they were slowly cooled (SC) after this heating.

No. 25. *Idem*. A piece of soft steel of 0.09 per cent. carbon, 3 mm. in diameter, was held for 64 hr. in illuminating gas at 1,000°, and then probably cooled slowly. It then contained 7.66 per cent. of graphite and 0.66 per cent. of combined carbon.

No. 26. Sauveur, *Journal of the Iron and Steel Institute*, vol. lxxii. (1906, No. IV.), p. 506.

No. 27. Royston, *Journal of the Iron and Steel Institute*, vol. li. (1897, No. I.), p. 166.

No. 28. Goerens and Gutowsky, *Metallurgie*, vol. v., No. 5, p. 137 (Mar. 8, 1908). Pieces, each weighing about 2 g., of white Swedish cast-iron, containing C, 3.91; Si, 0.12; Mn, 0.18; P, 0.02, and S, 0.008 per cent., were heated separately in a magnesia-lined porcelain boat, in an atmosphere of pure nitrogen, to 1,250°, held there 4 min., then cooled slowly to the temperatures indicated in this table, and then quenched in ice-water.



[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

**The Investigations of Fuels and Structural Materials by  
the Technologic Branch of the United States  
Geological Survey.\***

BY JOSEPH A. HOLMES, WASHINGTON, D. C.

(New York Meeting, February, 1908.)

**I. INTRODUCTORY.**

THE plans for the investigation of fuels and structural materials now being conducted by the Technologic Branch of the United States Geological Survey were, before being decided upon by the Director of the Survey, submitted for consideration to the National Advisory Board, upon which there are nine representatives from the membership of the American Institute of Mining Engineers, viz.: Messrs. John Hays Hammond, Robert W. Hunt, B. F. Bush, and E. V. d'Invilliers (representing the Institute); Messrs. Julian Kennedy and C. S. Robinson (representing the Iron and Steel Institute); Dr. Charles B. Dudley (representing the American Society for Testing Materials); Mr. F. H. Newell (representing the U. S. Reclamation Service); and Dr. Richard Moldenke (representing the American Foundrymen's Association). It seems fitting, therefore, that a report of these investigations of the past three years should be submitted to the Institute for publication in its *Transactions*.

The above, together with other representatives of the national engineering societies and allied organizations, were invited by President Roosevelt to serve, along with the Chiefs of the several Government Bureaus who have charge of public works and large fuel purchases, on the National Advisory Board to give advice concerning these investigations.

The appointment of this National Board grew out of a wish on the part of the President, the Secretary of the Interior, and the Director of the Geological Survey not only that the appropriations for these investigations be expended in a manner most beneficial to the several branches of the government

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service and without duplication of work well done elsewhere, but also that the investigations should be conducted in such manner as to make the results of the greatest possible benefit to the general public. And while the testing of materials for private parties has had no part in this general plan, the testing being limited (especially as applied to structural materials) to the materials belonging to or for the use of the general government, it is hoped that in view of the great variety of the materials tested, and the many different conditions under which the tests have been made, both of these general purposes may be accomplished.

## II. HISTORICAL SKETCH.

1. *The Fuel Investigations.*—This investigation of fuels had its beginning in an act of Congress providing for the analyzing and testing of coals and lignites of the United States at the Louisiana Purchase Exposition during 1904, under the supervision of the Director of the United States Geological Survey.

For carrying out the purposes of the two acts of 1904, each of which carried for this work an appropriation of \$30,000, Director Walcott appointed a committee consisting of Edward W. Parker, Marius R. Campbell, and Joseph A. Holmes, to which committee he assigned the supervision of the investigations thus provided for.

For co-operation in planning and conducting these investigations, the committee secured the services of Professor N. W. Lord, of the University of Ohio, as chief chemist; Professor L. P. Breckenridge, of the University of Illinois, consulting engineer in charge of the steaming-tests; and Professor R. H. Fernald, of Washington University, St. Louis, now of Case School of Applied Science, Cleveland, Ohio, as consulting engineer in charge of the producer-gas investigations. To the good advice and experience of these experts, as well as to the good work and wide knowledge concerning the coal fields of the country on the part of Messrs. Parker and Campbell of the committee, must be attributed a large share of the success attained in these investigations.

Early in 1905 the committee's supervision of these investigations was discontinued and the work placed under my charge. But the plans and methods developed by the committee during 1904 have, to a large extent, been continued in force, being

enlarged from time to time as a logical development of the progress made.

The legislation of 1904 provided that all of the testing-machinery and coals to be tested be furnished the government free of charge, but later much equipment was purchased.

The more important items of equipment secured in this manner were as follows: A producer gas-plant from Messrs. R. D. Wood & Co., of Philadelphia; a 250 h.p. gas-engine with auxiliary generator and considerable electrical appliances from the Westinghouse Co., of Pittsburg; two 210 h.p. boilers from the Heine Safety Boiler Co.; a 250 h.p. Corliss steam-engine and generator from the Allis-Chalmers Co.; two briquette-machines, one from Johnson & Co., of Leeds, England; another from the National Compressed Fuel Co., of Chicago; conveying-equipment from the Robins Belt Conveyor Co. and the Link-Belt Machinery Co.; and a lot of subsidiary equipment furnished by various parties; together with a coal-washing plant and three bee-hive coke-ovens. The four buildings necessary for the housing of this machinery were, however, paid for out of the government appropriation, as were also the fittings and equipment of a suitable chemical laboratory.

Early in 1907 the closing out of the affairs of the Louisiana Purchase Exposition necessitated the removal of the buildings from Forest Park, and consequently the removal of the Fuel-Testing Plant. At this time the Jamestown Exposition at Norfolk was approaching completion; the Exposition authorities there offered, free of charge, the use of necessary buildings, grounds and other facilities; the railways offered to transport from St. Louis to Norfolk, free of charge, all the necessary machinery and other equipment.

Meanwhile, a co-operative arrangement having been entered upon between the Departments of the Interior and Navy relative to the testing of coals suitable for naval purposes, it was decided to transfer to and operate at Norfolk all of the fuel-testing equipment except that for coking- and washing-tests, which latter was removed to and erected at Denver, Colo., for use in testing the coals of the Rocky Mountain States—especially those in lands belonging to the government.

The expediency of this removal of the plant was enhanced by the need of a brief period of inactivity in testing in order to

compute the results, prepare the necessary reports, and make chemical analyses of accumulated material and for similar duties.

In these ways the time of the technical force was fully occupied during the removal and re-erection of the plants, and the reports embodying the results of these investigations are now being published.

In connection with the work at Norfolk, it was felt at this time to be highly desirable to make steaming- and briquette-tests of the coals which reach the Atlantic seaboard for the use of the navy and the merchant marine. It was also considered important that these investigations at Norfolk include the possibilities of abating the smoke-nuisance on naval vessels, and in various public buildings burning bituminous coal. At the same time it was felt that this was an opportune time for investigating the possibilities of producing high-grade metallurgical coke from the coals of the Rocky Mountain regions, especially those on the public lands; and it was for this purpose that the coke- and washery-sections, removed from St. Louis, were erected at Denver, Colorado.

The Denver plant consists of a small office-building, a larger washery-building, including storage capacity of 150 tons of coal, and of two bee-hive coke-ovens. The temporary fuel-testing plant at Norfolk is housed in one large building, 300 by 125 ft., in one wing of which is placed briquette-machinery with necessary storage-bins; in another wing offices and chemical laboratories; in the central portion a boiler-plant, a gas-producer plant and the gas-engines, steam turbo-generators, gasoline-engines, etc.

Meantime, for convenience of analysis of fuels reaching the various testing-plants from all parts of the country, chemical laboratories were operated temporarily in Columbus, Pittsburg, Norfolk, Denver, and Berkeley (Cal.), and in the Geological Survey office in Washington, the latter for the special analyses of fuels purchased for the government.

2. *The Structural Materials Investigations.*—The investigation of structural materials in St. Louis was authorized by a Congressional appropriation early in 1905; and both the appropriation and the work were greatly enlarged during 1906. This work was a continuation of and followed logically from the in-

vestigations of cement-materials, building-stone, and clays which had been carried on to a limited extent by the Geological Survey for several years, and the cement-testing work which was inaugurated at St. Louis, during the Louisiana Purchase Exposition, by Mr. Richard L. Humphrey for the Association of American Portland Cement Manufacturers.

Through the courtesy and co-operation of the Louisiana Purchase Exposition Co. and the city of St. Louis, the investigations of fuels and investigations of structural materials were continued on the Exposition grounds during 1905 and 1906; and the investigation of structural materials has since that time continued at the same place, through the courtesy of the authorities of the city of St. Louis.

In April, 1907, these two lines of investigations—testing fuels and the testing of structural materials—were combined into two corresponding divisions—the fuel division and the structural materials division—and these included, by order of the Secretary of the Interior, in the Technologic Branch of the Geological Survey.

The structural materials investigations were at first housed in the Model testing-laboratory presented to the city of St. Louis by the Association of Portland Cement Manufacturers, after the Association had vacated the same at the close of the Exposition. Subsequent enlargement of the work made necessary the acquirement of additional buildings for the housing of the laboratories, and early in 1906 the Exposition authorities granted for this work the free use of two additional larger buildings—namely, a foundry-exhibit building, 100 by 125 ft., and a metal pavilion, 100 by 60 ft. The equipment in testing-machines and appliances is extensive, including one 600,000-lb. vertical screw testing-machine capable of use up to 800,000 lb.; four 200,000-lb. screw testing-machines; one 100,000 lb., one 40,000 lb., and numerous smaller automatic testing-machines, with auxiliary concrete-mixers, molds, etc. In addition, there are the necessary steam-boilers and engines, electric dynamos, gas-generators, etc., for the operation of the plant.

The Joint Committee on concrete and reinforced concrete of the several national engineering societies co-operates with the National Advisory Board in preparing programs of tests of materials for the government.

## III. FUEL INVESTIGATION.

*Plan and Scope.*—The scope of the fuel investigations has been planned to conform to the provisions of the law which provides for the analyzing and testing of coals, lignites, and other mineral fuel substances belonging to the United States, or for the use of the government of the United States, and examinations for the purpose of increasing the general efficiency or available supply of the fuel resources in the United States.

In conformity with this plan the investigations inaugurated at St. Louis had for their initial object the analyzing and testing of the coals of the United States, using in this work samples of from 1 to 3 carloads, collected with great care from typical localities in the more important coal-fields of the country, with a view to determining the relative values of those different fuels. In the work at Norfolk during 1907 this purpose was modified to the extent of keeping in view relative fuel-efficiencies for naval purposes. The tests at Denver are on coal from government land or from land contiguous thereto, and are conducted solely with a view to perfect the methods of coking this coal by prior washing and by manipulation in the process of coking.

It is no part of the plans or practice in connection with these investigations that tests of fuels be made for or at the request of private parties. On the other hand, the law provides that in the making of tests of fuels on lands not belonging to the government it shall be because of the fact that the sample to be tested shall represent extensive deposits, and that in such cases the published results shall not give the names of the owners of the mines from which the samples were collected for tests.

There are three general plans of the investigations undertaken and contemplated by the Technologic Branch, after conference and with the advice and approval of the National Advisory Board: 1. The ascertainment of the best mode of utilizing any fuel-deposit owned or to be used by the government, or the fuel of any extensive deposit as a whole, by conducting a more thorough investigation into its combustion under steam-boilers, conversion into producer gas, or into coke, briquettes, etc. 2. The prevention of waste, through the study of the possibility of improvement in the methods of mining, shipping,

utilizing, etc. 3. The inspection and analysis of coal purchased under specification for the use of the government, with a view to determining its heating-value, ash, contained moisture, etc.

1. The first general line of work concerns the investigation and testing of the fuel resources of the United States, and especially those belonging to the Federal government; to determine a more efficient and more economical method of utilizing the same with a view to the prevention of unnecessary waste. This work has developed along the following lines:

A. The collection of representative samples for chemical analysis and calorimeter tests by a corps of skilled mine-samplers, from the mines selected as typical of extensive deposits of coal in a given field or from a given bed of coal; and the collection from the same mines of larger samples of from 1 to 3 carloads of coal, shipped to the testing-station for larger scale tests in boiler-furnaces, gas-producers, etc., as a check on the analysis and calorimeter tests;

B. The testing of each coal received to determine the most efficient and least wasteful method of use in different furnaces suitable for public buildings or power-plants or ships of the government;

C. The testing of other portions of the same shipment of coal in the gas-producer for continuous runs during periods of a few days up to several weeks, in order to determine the availability of this fuel for use in such producers, and the best method of handling the fuel, with a view to determining the conditions requisite to produce the largest amount of high-grade gas available for power-purposes;

D. The testing of another portion of the same coal in each of two types of briquette-machines, at different pressures and with different percentages and kinds of binder, in order to determine the feasibility of briquetting the slack or fine coal. Combustion-tests are then made of these briquettes with a view to determine the conditions under which they may be burned advantageously;

E. Another portion of the same coal, if the ash- or sulphur-content were high, has been washed in the experimental washery-plant in order to ascertain whether this treatment improves the coal for steaming or coking sufficiently to repay the cost of washing;

F. Still other portions of each coal have before or after washing been tested in bee-hive coke-ovens in order to determine how it should be handled in such ovens to produce the largest output and best quality of coke. Owing to the lack of by-product coke-ovens, the testing of coals for by-product possibilities has been limited for the most part to chemical analyses;

G. At each stage of the process of testing, samples of the coal have been forwarded to the chemical laboratory for analyses; combustion-temperatures have been measured; and samples of gas collected from various parts of the combustion-chambers of the gas-producers and boiler-furnaces have been analyzed, in order that a study of these data may throw such light upon the processes of combustion and indicate such necessary changes in the apparatus as might result in larger economies in the use of coal.

2. The second line of investigation concerns the methods of mining and preparing coal for market and the collection of mine-samples of coal, oil, etc., for analysis and testing. It is well known that under present methods of mining from 10 to 75 per cent. of the coal is left underground as props and supports, or as "low-grade" material, or in overlying beds of coal that are broken up through mining the lower bed first, and that an average of 50 per cent. of the coal is thus wasted or rendered valueless, as it cannot subsequently be removed because of the caving or falling-in of the roofs of abandoned galleries and the breaking-up of the adjacent overlying beds, including coal, floor, and roof.

The investigations into waste in mining and the testing of the waste, bone and slack coal in gas-producer, as briquettes, etc., have for their purpose the prevention of this form of waste by demonstrating that these materials, now wasted, may be used profitably by means of the gas-producers and engines for power purposes.

3. The third general line of investigation concerns the inspection and sampling of coals delivered to the government under purchase-contracts, and the analyzing and testing of the samples collected to determine the heating-value of these coals, and the extent to which they may or may not comply with the specifications under which they are purchased. The coals delivered at the public buildings in the District of Columbia are

sampled by special representatives of the Technologic Branch of the Survey. The taking of similar samples at public buildings and posts throughout the United States, and the shipment of the samples in hermetically sealed cans or jars to the chemical laboratory in Washington, is for the most part looked after by special officers or employees at each place. These purchases are to an increasing extent made under specifications which provide premiums or penalties for coal delivered in excess of, or below, standards fixed in the specifications. The standard for bituminous coals is based mainly on the heat units, ash, and sulphur, while that for anthracite coal is, for convenience, based mainly on the percentage of ash.

In connection with all these lines of fuel-testing there is carried on a certain amount of research, chemical and physical work, with a view to determining the true composition and properties of the different varieties of coal, the changes in the transformation from peat to lignite, from lignite to bituminous, and from the latter to anthracite coal, and the chemical and physical processes in combustion. Experiments are conducted concerning the destructive distillation of fuels; into the by-products of coking-processes; into the spontaneous combustion of coal; into the storage of coal, and the loss in value in various methods of storing; and into kindred questions, such as the "weathering" of coal, which may yield valuable results through careful chemical research work supplemented by equally careful observations in the field.

*Some Results.*—The full value of such investigations as have been described above cannot be realized until many years after they were inaugurated. But even within the three years this work has been under way, certain investigations have already led to important results, some of which may be briefly mentioned as follows:

The chemical and calorific determinations of coals purchased for the use of the government have resulted in the delivery of a better grade of fuel without corresponding increase in cost, and have resulted in consequent saving to the government. The government under this system of purchasing its coal under specifications and testing is more nearly getting what it pays for and paying for what it gets. These investigations, by suggesting changes in equipment and methods, are also indicating

the practicability of the government's purchasing cheaper fuels, such as bituminous coal and the smaller sizes of pea, buckwheat, etc., instead of the more expensive sizes of anthracite, with a corresponding saving in cost. The fuel bill of the government now aggregates about \$10,000,000 yearly.

The making and assembling of chemical analyses and calorific determinations (checked by other tests) of carefully selected samples of coals from nearly 1,000 different localities in the different coal-fields of the United States, with the additions made from time to time representing parts of coal-fields, or additional beds of coal in the same field not yet examined, will be an invaluable source of accurate information not only for use of the government, but also for the general public. Of the above-mentioned localities, 501 were in the public-land States and 427 in the Central, Eastern and Southern States.

The tests of different coals under steam-boilers have also shown the possibility of increasing the general efficiency of hand-fired steam-boilers from 10 to 15 per cent. over ordinary results. If this saving could be made in the great number of hand-fired boilers now being operated in all parts of the United States, it would result in large saving in the fuel-bill of the country. Experiments which have been made with residence heating-boilers justify the belief that it will be possible to perfect such types of boilers as may economically give a smokeless operation for residence heating also. The tests under steam-boilers furnish specific information as to the most efficient method of utilizing each of a number of different types of coal in government buildings and power-plants in different parts of the country.

The tests in the gas-producer have shown that many fuels of such low grade as to be practically valueless for steam-furnace purposes, including slack coal, bone coal, and lignite, may be economically converted into producer-gas, and may thus generate sufficient power to render them of high commercial value.

Practically every shipment out of several hundred tested in the gas-producers, including coals as high as 45 per cent. of ash, and lignites and peats high in moisture, has been successfully converted into producer-gas which has been used in operating gas-engines. It has been estimated that on an average there was developed from each coal tested in the gas-producer

plant two and one-half times the power developed when used in the ordinary steam-boiler plant, and that such relative efficiencies will probably hold good for the average plant of moderate power capacity, though this ratio may be greatly reduced in large steam-plants of most modern type. It was found that the low-grade lignites of North Dakota developed as much power when converted into producer-gas as did the best West Virginia bituminous coals when utilized under the steam-boiler; and in this way lignite-beds underlying from 20,000,000 to 30,000,000 acres of public lands, supposed to have little or no commercial value, are shown to have a large value for power development.

The tests made with reference to the manufacture and combustion of briquetted coal have demonstrated conclusively that by this means many low-grade bituminous coals and lignites may have their commercial value increased to an extent that more than covers the increased cost of making; and these tests have also shown that the higher-grade bituminous coals may be burned in locomotives with greatly increased efficiency and capacity and with less smoke than the same coal unbriquetted. These tests have shown that the same locomotive can with the same fuel-consumption of briquettes as of raw coal very materially increase its hauling-capacity and thus reduce the cost of transportation.

The investigations into smoke-abatement have indicated clearly that each type of coal may be burned practically smokelessly in some type of furnace or with some arrangement of mechanical stoker, draft, etc. The elimination of smoke means more complete combustion of the fuel, and consequently less waste and higher efficiency.

The investigations into the waste of coal in mining have shown the enormous extent of this waste, aggregating probably from 300,000,000 to 400,000,000 tons yearly, of which at least one-half might be saved. It is being demonstrated that the low-grade coals high in sulphur and ash now left underground can be used economically in the gas-producer for power and light, and should therefore be mined at the same time that the high-grade coal is being removed. Moreover, attention is now being called to the practicability of further largely reducing this waste through more efficient mining methods.

The investigations into mine-explosives and explosions have pointed out some of the underlying principles concerning these, and have indicated the direction in which these investigations should be conducted hereafter with a view to indicating to users of explosives how the latter should be handled under varying conditions, in the presence of mine-gases and dust, and in the mining of different kinds of coal, etc., in order to avoid unnecessary waste of material or loss of human life.

The washing-tests have demonstrated the fact that many coals, too high in ash and sulphur for economic use under the steam-boiler or for coking, may be rendered of commercial value by proper treatment in the washery. The coking-tests have also demonstrated that by proper methods of preparation for and manipulation in the bee-hive oven, many coals which were not supposed to be of economic value for coking-purposes may be rendered so by proper prior washing and proper treatment. Of more than 100 coals tested during 1906 from the Mississippi Valley and Eastern States, most of which coals were regarded as non-coking coals, all except six were found by careful manipulation to make fairly good coke for foundry and other metallurgical purposes. Of 37 coals tested from the Rocky Mountain region, all but three produced good coke under proper treatment, though a number of these were considered as non-coking coals.

Investigations into the relative efficiency of gasoline and denatured alcohol as power-producers, undertaken in connection with work for the Navy Department, have demonstrated that with proper manipulation of the carburetters, igniters, degree of compression, etc., denatured alcohol has the same power-producing value, gallon for gallon, as has gasoline. This is a most interesting development in view of the fact that the heat-value of a gallon of alcohol is only a little more than 0.6 that of a gallon of gasoline. To secure these results, compressions of from 150 to 180 lb. per sq. in. were used, these pressures involving an increase in weight for the size of engine over those used for gasoline. Although the engine especially designed for alcohol will be heavier than a gasoline-engine of the same size, it will have a sufficiently greater power capacity so that the weight per horse power need not be greater.

Several hundred tons of peat have been tested to determine methods of drying, compressing into briquettes, and utilization for power-production in the gas-producer. In connection with those peat-investigations a reconnaissance survey has been made of the peat-deposits of the Atlantic Coast. Samples have been obtained by boring to different depths in many widely distributed peat-bogs, and these samples have been analyzed and tested in order to determine the origin, nature, and fuel-value.

*Extent of the Work.*—The extent and number of tests from which these results have been derived will be appreciated from the fact that more than 10,000 tests and analyses were made, in each of which large quantities of fuel were consumed. These tests involved nearly 1,250,000 physical observations and 37,200 chemical determinations, made with a view to analyze the results of the tests and to indicate any necessary changes in the methods as they progressed. For coking, cupola, and washing, 174 tests, of which 90, involving the use of 477 tons of coal, have been made at Denver in the last six months. For briquetting, 338 tests, of which 38, involving the use of 935 tons of coal, have been made at Norfolk in the last six months. As showing the combustion-tests to which these briquettes have been put during the past six months at Norfolk, 250 tons of briquetted coal were consumed in battleship-tests; 210 tons were consumed in torpedo-boat tests; 320 tons on locomotive-tests on three railway-systems; and 70 tons were consumed under stationary steam-boilers; 163 gas-producer tests have been made, of which seven were long-time runs, of one or more weeks' duration, consuming in all 105 tons of coal; 540 steam-boiler tests and 74 house-heating boiler-tests have been made, the tests of the last six months using 135 tons of coal. There have also been made 83 railway-locomotive and 23 naval-vessel tests on run-of-mine coal in comparison with briquetted coal. There have been made 125 tests in connection with heat-transmission experiments, and 2,254 gasoline- and alcohol-engine tests. More than 3,700 samples of coal were taken for test or analysis, of which 1,042 were from public-land States. Nearly 1,100 inspection-samples of coal purchased by the government for its use have been taken and tested. In connection with the explosives investigations, 350 analyses

and tests have been made, both upon samples submitted by the Reclamation Service and the Isthmian Canal Commission in connection with payment upon purchases, and also in connection with investigations into the explosives generally used in mining.

*Publication of Results.*—The results of tests so far made in the course of these investigations, and as above summarized, have been published in ten separate bulletins, three of which set forth in detail the operations of the Fuel-Testing Plant for the years 1904, 1905, and 1906, and a fourth, consisting of a Professional Paper in three volumes, describes in greater detail each stage of the operations for the years 1904 and 1905. There has been published a separate bulletin descriptive of the Methods and Results of the Work of the Chemical Laboratory. Another bulletin outlines and details the Methods and Results of 400 Steam-Boiler Tests. There is a bulletin descriptive of Mine Accidents and their possible prevention. Still another deals with the Burning of Coal Without Smoke, describing the methods necessary to this end in government buildings and elsewhere. Another bulletin describes in detail the Results of the Operations of Washing, Coking and Cupola Tests, and the last of the bulletins so far issued describes the Specifications for Coal Purchase now in force in connection with the inspection of the purchase of coal for the use of the government.

In addition to these publications, there is in press a bulletin describing the Results of Tests of Binders for Briquettes, and there are in preparation a bulletin setting forth in detail the Results of all the Chemical Analyses and Field Sampling on which they are based, so far as made in the course of the operations of the Fuel-Testing Plant; a bulletin outlining the Causes of Waste of Coal in Mining; one describing in full the Results of Combustion of Briquettes on Locomotives, both in the United States, by the Fuel-Testing Plant, and in Europe; a bulletin giving in detail the Results of Producer-Gas Tests so far made; a bulletin outlining the Results of Comparative Gasoline and Alcohol Tests; and two additional bulletins on the subject of Mine Explosions and of Smoke-Abatement Appliances.

*Future Plans.*—As already stated, all plans for investigations, both of fuels and structural materials, are, before being decided upon, submitted in writing to members of the National

Advisory Board—which includes representatives of the national engineering and allied societies and a number of government bureaus.

The plans for future work not yet having been passed upon by this Board and the Director of the Geological Survey, naturally cannot now be offered for publication. It may be said, however, that they will be in furtherance of the larger purposes of this investigation, viz.:

- (1) Determining the nature and extent of the waste in the mining of coal, and the extent to which it may be practicable to lessen this waste;
- (2) The possibilities of reducing the waste and increasing the efficiency in the burning of coal for different purposes, especially in the public buildings and power-plants of the government;
- (3) The testing of the fuels purchased for use by the government, with a view to determining their value and how they can be used most efficiently;
- (4) Determining the value and best methods of utilizing the fuel-resources belonging to the government.

#### IV. STRUCTURAL MATERIALS INVESTIGATIONS.

*Work Now in Progress.*—These investigations are being conducted with a view to determining the nature and extent of the materials belonging to or available for use in the building and construction work of the government, and how these materials may be used most efficiently.

It may not be amiss to call attention again to the fact that no testing or investigations are conducted for private parties. At the same time, it is believed that both the ordinary tests and the investigations, though conducted to meet the needs of the government, cannot fail to be of great value to the engineering profession and the general public. The building and engineering construction work of the Federal government now aggregates about \$40,000,000 annually; and this work is being done under so many different conditions and requires so great a variety of materials, that the problems which the government needs to have solved for its own purposes can hardly fail to be broad enough to cover a large share of the needs of the engineering profession, for State and municipal governments, and for the general public.

These investigations include inquiries into :

- A. The nature, extent and distribution of materials such as are needed for use by the government;
- B. How they can be used most efficiently under different conditions;
- C. Their fire-resisting qualities and strength at different temperatures;
- D. How the steel supports in building construction can best be protected from fire by inclosing them with thicknesses of different fire-resisting materials, and the strength of these supports at different high temperatures;
- E. The value of protective coatings as preventive of deterioration of structural materials by destructive agencies;
- F. The extent to which concrete made from cement and local materials can be most safely and efficiently used for different purposes under different conditions;
- G. The materials suitable for the manufacture of cement on the public lands or elsewhere in the country where the government has planned extensive building or engineering construction work and where no cement-plants now exist;
- H. The best methods for mixing and utilizing the various constituent materials locally available for use in government construction;
- I. The kinds and forms of reinforcement for concrete and the best methods of applying such reinforcements to secure the greatest strength in compression, tension, shear, etc., in reinforced concrete beams, columns, floor-slabs, etc.;
- J. The influence of acids, oils, salts and other foreign materials, long-continued strain, or electric currents on the permanence of the steel in reinforced concrete;
- K. An investigation of clays and clay-products needed in government work, and the most efficient methods of testing clays and clay-products;
- L. An investigation into the building-stones available near the building centers in the various parts of the country where the government is planning extensive building or construction work;
- M. The establishment of working-stresses for various structural materials needed by the government in its buildings.

In addition to the large extent and variety of building and

construction work of the government, the amounts expended by the several municipalities and the people of the country in building and construction work now exceed \$1,000,000,000 per annum, of which more than one-half is represented in structural materials.

The scope of the structural materials investigations necessarily includes examination of the various constituent materials in the field, the collection and shipping of samples to the testing-laboratories, the assembling of these samples into various structural forms, and the testing of these forms to determine the best method of mixing and seasoning such materials.

The cement used in these investigations was prepared by thoroughly mixing half a dozen Portland cements of well-established brands. All other constituent materials used were collected in the field by trained experts, with due regard to the nature and extent of the available supplies of such materials. Each series of tests is therefore not only a contribution to our knowledge of the properties and behavior of concrete, but also a contribution to our knowledge concerning the structural materials resources of the country.

While the purpose of these investigations is to meet the government's own needs as the greatest consumer of structural materials, incidentally the results will be generally useful to the various States and municipalities, and to the people of the whole country. Finally, these investigations are so planned as to make use of and to correlate all similar work by others, either in State testing-laboratories, in the testing-laboratories of the various universities, and through the agencies of the engineering societies and their joint committees, etc.; all this work with a view to avoiding all unnecessary duplication, and securing thereby the wisest expenditure of all funds available for such investigations from whatever source.

The work in the past has been confined largely to the constituent materials of concrete and the concrete itself, the funds available being too limited to admit of a more rapid extension of this work to other structural materials, and this being the material concerning which there was the greatest demand for information by the various branches of the government service. During the next fiscal year, however, it is proposed to take up

on a larger scale the additional subjects heretofore neglected, in accordance with the above brief statement.

In the plans for all these tests and investigations due consideration is given to the good work done at the testing-station of the Watertown Arsenal and in the laboratories of educational institutions, with a view to avoiding duplication.

*Some Results of Tests.*—Until recently the results obtained from the investigations of structural materials by the Geological Survey have seemed to be slow in forthcoming. The obvious reason therefor is the fact that elaborate and expensive testing-apparatus had to be designed, purchased, and installed. After nearly a year of preparation there was further delay in securing results, due to the necessity of giving the test-pieces of cement, mortar or concrete sufficient time in which to season for the requisite 7-day, 28-day, 3-, 6-, 12-, 18- and 24-month testing-periods. Finally, the time-element has been felt in the digestion of the results of the tests, due to the involved computations necessary in order that the vast number of tests made might be intelligently discussed. Happily, these inaugurating periods of preparation have in a measure passed and the results are now forthcoming rapidly.

There have been made at the structural materials testing-laboratory more than 39,300 separate test-pieces, upon which nearly 53,000 tests have been made, and in connection with the study of which over 10,400 chemical determinations have been made. Of these tests nearly 27,800 have been of the constituent materials of concrete, including tensile-tests of cement-briquettes, compression-tests of cylinders and cubes, and transverse-tests of various specimens, etc.

There have been made nearly 1,100 beams of concrete or reinforced concrete, each 13 ft. long and 8 by 11 in. in cross-section. There have been made a total of over 2,500 tests in connection with the investigation of the behavior of these beams. Tests have been made on 870 of these beams, or probably more than double the entire number that has been made in other laboratories in this country during a period of more than 15 years.

In the section of building-blocks, 2,200 blocks have been tested. Also, more than 900 pieces of concrete have been tested for permeability and shear. Physical tests have been made to

the number of nearly 13,000; tests of steel for reinforcement to the number of 3,500; and tests to determine fire-resisting qualities of various building materials have been made on 30 special panels.

While the time since the inauguration of this work has been entirely too short to warrant a serious questioning as to resulting money-returns to the government, yet a few general beneficial results are mentioned below, though a number of specific items that might be mentioned are omitted for lack of space.

Reconnaissance survey has been made of constituent materials near several building centers and locations for engineering construction, at requests from the Supervising Architect, Corps of Engineers, U. S. A., U. S. Reclamation Service, and other branches of the government service.

Tests of these constituent materials, including sand, gravel, broken stone, and gravel and stone screenings, assembled into mortars and concretes, indicate clearly where the government may find these most convenient and economically available for construction of public buildings and engineering works.

Special tests of more than 1,000 plain and reinforced concrete beams, floor-slabs, columns, etc., are demonstrating the proper method of proportioning the constituent materials and of placing the reinforcing and the amount thereof to secure for each group of materials locally available the most efficient and economic results for the building and engineering construction work of the government.

These tests indicate the possibility of reducing the amount of materials necessary, and of thereby producing economies of upwards of 10 per cent. in design of public buildings and structures using wholly or in part reinforced concrete construction. It is well known that through present lack of knowledge of behavior of concrete and reinforced concrete, high factors of safety, involving the use of excessive quantities of material, are now necessary in designing structures of these materials.

As a single illustration of how these investigations, conducted to meet the needs of the general government, may incidentally be of service to the engineering profession or to State or municipal governments, it may be mentioned that the investigations of the sands and gravels in the vicinity of Louisville, Ky., for the use of the Supervising Architect of the Treasury Depart-

ment and the Corps of Engineers of the Army, are said by the engineers in charge of the new sewer-system of that city to have saved the city in that construction work not less than \$100,000.

*Publication of Results.*—The results of this work have already appeared in three preliminary bulletins, for which the demand far exceeded the supply—(1) describing the effects of the San Francisco Earthquake and Fire; (2) setting forth in detail the Organization, Equipment and Method of Testing at the Structural Materials Laboratory at St. Louis; and (3) giving the Results of 25,000 Tests of Constituent Materials of Concrete. This latter is probably the most extensive series of tests of this kind ever undertaken, and probably exceeds in number all the tests of this nature heretofore made in this country.

There is in course of publication a bulletin giving the Results of Tests with 108 Plain Concrete Beams, which should be ready for issuance within a few weeks. In addition to this bulletin, there are in preparation the following, which will shortly be ready for publication, viz.: A bulletin giving the Results of the Fire Tests of 30 Panels of Various Building Materials; a bulletin giving the Results of the Tests made in 1905 at Various Colleges and Universities; a bulletin giving the Results of Tests of 252 Reinforced Concrete Beams; another outlining Results of Tests of Series of 90 Reinforced Concrete Beams; and, finally, bulletins setting forth the Results of Tests of Mortar Building-Blocks, the Results of Tests of Reinforced Concrete Slabs, and the Results of Additional Tests of Constituent Materials of Concrete.

The above are considered in a measure as preliminary statements of immediate results. They will be followed as promptly as possible with other bulletins, in which the results of all the tests mentioned on any special phase of the subject will be brought together, carefully digested, and rendered more easily available for use of engineers, architects, and builders.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

## Effect of Humidity on Mine-Explosions.

BY CARL SCHOLZ, CHICAGO, ILL.

(Birmingham Meeting, October, 1908.)

DURING November and December, 1907, four serious mine-explosions occurred in the Appalachian coal-field, which resulted in the loss of nearly a thousand lives and caused an enormous damage to property. These accidents attracted more than the usual attention; coal-trade and engineering papers contained many comments and suggestions on the cause and prevention of accidents; the daily press in many instances condemned the coal-operators and charged these accidents to their negligence, or their anxiety to make money without adopting precautionary measures. Immediately after each accident the respective State authorities ordered close investigations to be made, with the view of establishing the cause and suggesting remedies to prevent recurrence. Representatives of the Technologic Branch of the U. S. Geological Survey, to whom the investigation of mine-accidents had recently been delegated by the Secretary of the Interior, visited the mines and co-operated with the local authorities in their determinations. It may be safe to say here that an investigation of a mine after an explosion has occurred discloses but little, because the causes have been removed and conditions have been entirely changed.

On Jan. 8, 1908, the coal-operators of West Virginia organized an association at Washington for the purpose of making extensive investigations, and sufficient funds were pledged to carry out this work. At this organization meeting, the representatives of the Geological Survey present had no suggestions to offer as to the cause of these accidents.

An examination of the various reports concerning these accidents indicates that the explosions were caused by the ignition of gas or dust; they show the point of origin and the direction in which the force was expended, and give a detailed description of the damage done. Very little has been said as to what

should be done to prevent these explosions, and the object of this paper is to give the result of several years' observation of conditions which I have noticed during 15 years' connection with coal-mines in various fields of the United States.

The striking features developed by these investigations are:

1. Explosions occur more frequently in the colder months of the year; the colder the winter the more frequent the explosions. If a certain district has extremely cold weather and other sections of the country are comparatively warm, the latter sections are freer from explosions.
2. Mining fields located in higher altitudes are more productive of explosions than those at lower elevations.
3. The hygrometric condition of the atmosphere has the greatest effect upon the cause of explosions.

Every practical mining man knows that the majority of explosions take place between Nov. 1 and Mar. 15. It is well to say here that there are many explosions of a minor character which result in no loss of life, or perhaps one single death only, of which but little is published in the daily or technical press. Every mine-examiner instinctively feels danger when he enters the mine on a cold crisp morning.

The fact that altitude and general climatic conditions enter into mine-explosions can very readily be verified by an examination of the weather reports showing the general climatic conditions which existed in the various localities when accidents have happened.

The principal fields of mine-explosions in the bituminous districts are Pennsylvania, the eastern portion of West Virginia, Alabama, Oklahoma, and Colorado; and since coals produced in these fields are high in volatile matter and low in moisture, it is very clear that the chemical composition of the coal has much to do with the generation of mine-gases and coal-dust.

In examining the records of explosions in West Virginia, it will be noted that most of them occur during unusually cold weather, and but few in the warm season when the trees are in full foliage. In Oklahoma the record indicates that the greatest number of explosions have followed an unusually dry season. It should be noted that this portion of the country is not densely timbered, and contains but limited bodies of flowing

water. The same condition applies to Colorado to an even greater extent.

The two conditions above mentioned, when taken in connection with the visible results which they create in the mine by the deposit of excess of moisture during the wet season, or when humidity is high, and the creation of dust during the winter months or the very dry season, undoubtedly lead us to believe that the hygrometric condition of the ventilating-currents has much to do with mine-explosions; and since this is a matter which can be controlled without much expense, it is believed that the application of a vaporizing-system in mines which are dusty and generate fire-damp will prove, at least in part, a remedy.

After examining many text-books and reports, I noticed that very little reference is made to the hygrometric condition of the atmosphere in connection with mine-explosions. The only reference is given by William Tate.<sup>1</sup> Some of the more recent publications refer to the advisability of ascertaining the moisture in the air, but do not state the effect which humidity has, and how the required degree of saturation should be brought about. That humidity in a mine-ventilating current is desirable and necessary, is generally understood, and is emphasized by the recommendation usually made by mine-inspectors that roadways be sprinkled with water in order to settle the dust. The adoption of appliances to settle the dust will prove the best safeguard against mine-explosions.

One of the most striking remarks on this subject was made by Mr. Samuel Dixon before the meeting at Washington above mentioned. He said that mine-explosions began to occur as soon as improved ventilating-fans of high efficiency were adopted, and that as long as the mines were ventilated by furnaces and fire-baskets, mine-explosions were practically an unknown condition. This statement is true in so far as in summer very little water was carried into the mine, and in winter very little was taken out, as is shown by the following statements.

The mines of Oklahoma offer special facilities for the observation of the effect of climatic and hygrometric conditions upon explosions, because the coal is high in hydrocarbon and low in moisture; the outside temperature ranges from 90° F. in the

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<sup>1</sup> *Questions and Answers for American Mine Examinations*, p. 27.

summer to  $10^{\circ}$  F. in the winter, and the hygrometric condition has a wide range, because of the excessive rain in the summer, which is followed by a prolonged dry period in the fall and winter. The observations inside the mines are facilitated by the noticeable effect which humidity has upon the roof during the wet season and the number of explosions which usually occur during the cold, dry season. I therefore selected the mines in this field for a series of observations which were carried on during the past 18 months.

The first purpose of these investigations was to stop the slackening of the roof, which occurs during the "sweaty" season, beginning about May 1 and lasting until the middle of July. During this period a heavy deposit of moisture on the roof causes the slate to slack, especially on the in-take air-ways and near the place of in-take. On account of the high cost of timber, this condition considerably increases the production-cost. From August to November the mines become very dry, and are very dusty for the next three or four months, during which time explosions occur. One fortunate condition in this field is the fact that the veins are pitching, and the water usually runs along the entries, although the beneficial effect of this condition is not generally understood or appreciated.

Observations indicate that when the outside temperature ranges from  $75^{\circ}$  to  $90^{\circ}$  F., the inside temperature fluctuates from  $72^{\circ}$  to  $76^{\circ}$  F. In the winter, when the outside temperature ranges from  $30^{\circ}$  to  $55^{\circ}$  F., the inside temperature ranges from  $60^{\circ}$  to  $64^{\circ}$  F. In the summer, when the warm-air current enters the mine, the temperature falls upon coming in contact with the cold ribs along the entries, and the excess vapor is deposited as sweat on the roof and the roadways, so that no dust exists. The mine, of course, becomes drier nearer the up-cast, since a part of the humidity is absorbed by the freshly-mined coal. In the winter, when the inside temperature is higher than that of the air outside, the cold ventilating-current, upon warming and expanding, absorbs all the moisture available. If there is no water available, the relative humidity in the air-current is very low. For the purpose of illustrating this more clearly, the following data, representing actual readings, will be of interest:

With an outside temperature of  $80^{\circ}$  F. and relative humidity

of 75 per cent., at a barometric pressure of 29.2 in., a ventilating-current of 75,000 cu. ft. per min. carries into a mine, invisibly suspended in the air, during a period of 24 hr., 15,200 gal. of water. Upon cooling to a temperature of 75° F., not only would the mine-current be completely saturated, but there would be deposited in the mine nearly 1,000 gal. of water per day. In the winter, however, with a temperature of 32° F. and a relative humidity of 95 per cent., upon entering the mine and warming to 62° F., the relative humidity of the ventilating-current is diminished to 33 per cent., unless an opportunity is given for the air-current to absorb more moisture from running water or other sources. In order to saturate completely this warmed air-current of 75,000 cu. ft. per min., about 9,000 gal. of water per day is required. This is the reason why dust is generated in the winter in the better-ventilated mines, as stated by Mr. Dixon, and the assumption is well borne out by the accident at the Monongah mines, which had a ventilating efficiency of the highest order. The more cold air forced through a mine in the winter, the drier will that mine become; the more air forced into a mine in the summer, the more moisture will be deposited along the in-take entries, and where the roof is slate, the more difficulty will be experienced in keeping up the top. It is also well known that humidity in the air has an effect upon the ignition of gases, because the fine particles of water invisibly suspended in the atmosphere absorb much of the heat in combustion. For comparison, it may be said that an air-current of a temperature of 62° F., fully saturated with moisture, requires approximately 7 per cent. more heat-units (B.t.u.) than dry air to reach a temperature of 1,213° F., which is the point of ignition of fire-damp.

A water-spraying system, consisting of a number of small sprays distributed over the first half of the distance which the air-current traverses, will have the effect of preventing the formation of dust and moistening the gaseous mixture. The sprays should be placed near the roof, and discharge the water in the direction of the air-current. This arrangement will have an additional beneficial effect in mines generating much fire-damp, the descending water-spray serving to break up any stratification of gases that may exist in the entries. The proper quantity of water to be vaporized will depend upon altitude,

climatic conditions and character of the coal. The only danger to be guarded against is the use of an excessive amount of water, which would result in cutting a slate roof; if coal or sand-rock prevails, no limit need be established, because, with the lower temperature in the mines in this country, the danger which was pointed out by the British Colliery Commission, that excessive humidity injuriously affects the health of the miner, does not exist, the temperature of the English mines being from 90° to 95° F.

A large number of readings taken throughout the various seasons of the year in the Oklahoma mines, indicate that in the summer at the up-cast the relative humidity rarely falls below 75 per cent. Theoretically, the air-current should be fully saturated; the discrepancy can only be explained by the statement that the freshly-mined coal and the dust incident to mining absorb the difference. In winter, the drop in the relative humidity in a dry mine is very striking; and attention is drawn to the fact that in mines where shot-firers are employed, when explosions occur, they usually happen directly after the first few shots are set off, which must be due to the condition that the relative humidity at the point of up-cast is much lower, because what little water was contained in the down-cast was absorbed by the workings through which the ventilating-current first traveled.

A series of analyses of air were also made, and samples of air were taken in the mine at the end of a day's work, and again from the same point after the mine had been standing idle for 48 hr. The ventilating-current was maintained at a uniform rate, and there was no appreciable change in the atmospheric pressure. The first analysis showed that 0.05 per cent. of methane existed in the air-current next to the floor, which increased to 1.5 per cent. near the roof. The explanation of this condition is that the travel of trips and men through the mine-workings, and the fluctuation of the ventilating-pressure, due to the opening and closing of trap-doors, thoroughly mixed the air-current and prevented the stratification of the gases. The second analysis showed no methane near the floor, but 5 per cent. near the roof, which indicates that the comparative quiet and smooth travel of the ventilating-current during the idle period aided the stratification of the gases. This theory is borne out

by readings with a self-recording pressure-gauge, which showed many violent fluctuations during the day, and produced a practically straight line during the night.

The advantage of a spray, therefore, is that the vapor will break up stratification and mix the gases over the entire cross-section of the entry. This action can be repeated as often as necessary by the spacing of the sprays, and the requirements can easily be determined by hygrometer-readings and gas-tests. There would be no advantage in or necessity of operating these sprays during the summer, unless indicated by hygrometer-readings in very dry mines. The sprays used in conducting these experiments, and now used in several of the mines under my management, are manufactured by Paul Lechler, Stuttgart, Germany; but there are several manufacturers in the United States who produce similar apparatus which can be adapted to suit the conditions, as, for instance, the American Moistening Co., of Boston.

The principal benefit derived from sprinkling water by means of water-boxes or hose-lines, as now generally practiced and recommended, is that moisture is provided for absorption by the dry mine-air. As far as the settling of dust is concerned, unless the sprinkling is very thorough and often repeated, the results are not satisfactory, because a deposit of coal-dust is impervious to water unless thoroughly mixed with it; a thin moist coat will form on the surface, beneath which the dust is as dry as ever. The cost of labor in this method of sprinkling is very high and the service performed is spasmodic, and unless constantly looked after by foremen or superintendents it is likely to be neglected. The advantage of a spraying-system is that, in addition to preventing the formation of dust, the sprays can be utilized to prevent stratification of gases at night or on idle days, and this advantage can be obtained at a cost of installation but little greater than that of the hose system, as it involves only the addition of spray-boxes at a cost of \$2 each. There is no expense connected with this, because most mines employ pumpers on idle days and at nights, and the shaft pressure can be used in the sprays; or if this is not convenient, in most places some outside supply can be connected which will insure continuous operation. It is believed that the operation of such a spraying-system, by reason of the continuous and

automatic protection which it furnishes to the mines, is the most economical, and at the same time the most important step which coal-operators can take to safeguard their mines.

I recommend that mining engineers and coal-operators, in fields subject to gas-explosions, obtain, for their own information, a record for a year, taken once a week, both outside and at the point of up-cast, to show the temperature and relative humidity, and from these results compute the amount of water which is carried into and taken out of the mine. It is predicted that the results will be astonishing to a great many.

Many conditions exist showing the effect of relative humidity upon everyday life, which were not comprehended for a long time. As an illustration, the textile-manufacturing business was very unsatisfactorily conducted in the United States compared with England, and it was only with the adoption of air-moistening apparatus that the manufacturers were able to improve the product, the relative humidity in England being so much higher by reason of the proximity to large bodies of water and natural damp conditions. Again, the introduction of breakfast foods in England by American manufacturers proved an absolute failure, because of the rapid absorption of water, which resulted in mold.

Likewise, it is safe to believe that if English mines could be transferred to Oklahoma or Colorado, they would become very unsafe by reason of the change in the climatic conditions; and, *vice versa*, if we could move our Oklahoma mines to England they would be very safe. Gas rises more rapidly in an atmosphere free from humidity, as is demonstrated by the ascent of chimney smoke on a cold crisp morning; and conversely, the opposite condition prevails in foggy weather. Likewise do gases rise to the roof of the mine and accumulate there in dry atmosphere; if the air is moist the ascent will be much slower.

Another comparison between the conditions in a mine and dry and wet weather may be made by the operation of internal-combustion engines. The consumption of gasoline in the summer is much greater than in the winter in the same climate; in the warm weather the excess of humidity present in the mixture absorbs a certain amount of heat-units before the vapor develops effective power; consequently, an automobile consumes more fuel in the summer than it does in the

winter under the same conditions. A gaseous mixture containing dry air becomes explosive with a much smaller percentage of methane, and the higher the ratio of humidity in the mine and the ventilating-current the less is the danger.

I respectfully invite comment and criticism on the opinions set forth in this paper, and I will gladly answer in detail any discussion by members of this Institute.



## Requirements of a Breathing-Apparatus for Use in Mines.

BY WALTER E. MINGRAMM, NEW YORK, N. Y.

(Birmingham Meeting, October, 1908.)

THE construction of rescue-apparatus on the principle of furnishing the wearer with air from a tank containing it under high pressure was given up by inventors about 20 years ago. Such an apparatus must supply continuously, for not less than two hours, nearly 50 liters of pure air at atmospheric pressure per minute, or a total of 6,000 liters (210 cu. ft.); and a cylinder containing this amount of air, under 2,000 lb. pressure, would weigh 180 lb. or more.

Although apparatus has been recently constructed utilizing liquified air, no experiments have been made to determine the regularity with which the air is generated, nor has its chemical composition been determined. Moreover, the chief objection to such an apparatus is the difficulty and cost of keeping on hand a large quantity of liquified air.

The system of furnishing the wearer of a breathing-apparatus with air which has given the best results, and has found employment in all the devices now in practical use, is that in which the air contained in the human lungs at the beginning of the work is regenerated by the apparatus. By means of chemicals, such as caustic potash and caustic soda, the carbonic acid gas,  $\text{CO}_2$ , exhaled is absorbed, and the oxygen that has been consumed is replaced from a tank containing this gas under high pressure. The pressure of the oxygen (which is 1,875 lb. in the two cylinders at the beginning of the work) is automatically reduced to 75 lb., and is sufficient to keep the air inside of the apparatus in constant circulation, and to force it to pass through the chemicals provided for the absorption of the  $\text{CO}_2$  gas.

In the attempt to construct an apparatus which would (1) furnish the wearer with a sufficient supply of air; (2) replace the amount of oxygen used up by the lungs during the time of

two hours, and (3) thoroughly absorb the carbonic acid gas exhaled during the same period, a number of interesting experiments have been made by Mr. Bernhard Draeger, the inventor of the life-saving apparatus which bears his name.

Concerning the amount of air which a person requires during hard work, few facts were known until very recently. Generally, it was supposed not to exceed from 16 to 20 liters per min. Experiments made with three different individuals (the exhaled air being measured by a so-called spirometer or gasometer) have given the following average figures:

|   | Quantity of Air<br>Required for 1 Min.<br>Liters. |
|---|---|
| A person sitting down, . . . . .  | 8.5   |
| A person after a walk of 1,000 ft., . . . . .                           | 11.5  |
| A person after marching over 2,000 ft., . . . . .                       | 16  |
| A person lifting heavy weights, . . . . .                               | 35  |
| Two persons, in a stooping position, carrying a third person, . . . . . | 30  |
| A person racing over a distance of 900 ft., . . . . .                   | 50  |

On the basis of these figures, a rescue-apparatus which will enable its wearer to do any kind of hard work must furnish not less than 50 liters per min. during the entire working-time of two hours. The Draeger apparatus meets this requirement.

During heavy work, and particularly after, there is always a period of a few seconds during which the amount of air required is momentarily increased to even more than 100 liters per min. A life-saving apparatus can only secure absolute safety if it assists the workman unconsciously and without becoming oppressive during even the heaviest breathing. This requirement, also, is met in the construction of the Draeger apparatus.

It is therefore necessary to know the quantity of oxygen that must be supplied by a rescue-apparatus. The amount of oxygen used up by the lungs during rest is ascertained to be about 0.3 liter, gradually increasing to 1.75 liters during the very hardest work (such as requires a circulation of air up to 50 liters per min.). Hence, an apparatus that will permit the wearer to do any kind of hard work must supply not less than 2 liters of pure oxygen per minute.

Contrary to some assertions, it is useless to increase further the amount of oxygen in the hope of overcoming the harmful effects of carbonic acid in the air breathed. Unfortunately,

oxygen does not have this quality, and its beneficial effects commence only when the air is free from carbonic acid. The development of the life-saving apparatus, since the first were constructed, about 20 years ago, shows a constant battle against the carbonic acid, which could not be done away with. Only an apparatus that will furnish its wearer with a circulation of air, always nearly free from this gas, will be thoroughly satisfactory. Careful experiments have shown the following:

| Carbonic Acid Contained in    | Parts per Thousand. |
|-------------------------------|---------------------|
| Bad room-air, . . . . .       | 2                   |
| Unhealthy air, . . . . .      | 10                  |
| Dangerous air, . . . . .      | over 20 to 25       |
| Very poisonous air, . . . . . | over 30             |
| Deadly air, . . . . .         | 40                  |

According to these figures, a rescue-apparatus should never allow the amount of carbonic acid contained in the circulated air to exceed 10 parts per thousand.

Very interesting experiments were made by Mr. Draeger to ascertain: (1) the amount of carbonic acid contained in the respiration-air of different apparatus; (2) how this amount of carbonic acid affected the wearer of the respective apparatus; and (3) how far the working-power of the wearer was reduced on account of the presence of carbonic acid in the circulating air.

A number of tests, made under the supervision of a chartered chemist, have shown that a workman using an apparatus in which, during the two hours of working-time, the amount of carbonic acid did not rise over an average of 2 per 1,000, was able to do work equal to moving 35 tons through a distance of 1 m.; a workman using an apparatus in which the carbonic acid rose to 20 per 1,000 on an average, was obliged twice to be taken out of the smoke-chamber in a faint, and the work done hardly amounted to 20 tons. The work was registered by a machine, the workman lifting a weight of 25 kg. through a distance of 1 meter.

Experiments have further shown that the working-power of a man is reduced only 9 per cent. by wearing a Draeger apparatus, in which the quantity of  $\text{CO}_2$  was only 2 per 1,000.

The foregoing shows that, besides a sufficient circulation of air and a sufficient supply of oxygen, the most important factor

in the construction of a rescue-apparatus is the thorough absorption of the carbonic acid produced by the lungs. In fact, years of experience in working with rescue-apparatus in mine-fires and explosions has convinced me that an apparatus will be of practical value only when its construction fulfills this requirement.



FIG. 1.—THE DRAEGER APPARATUS. FRONT VIEW.

The weight of the different kinds of breathing-apparatus is about 30 lb. each, the variation being hardly more than one or two pounds, which, of course, is of little consequence. Of the lighter forms that are on the market none have met with success, on account of the insufficiency either of the supply of oxygen or of the absorption of carbonic acid. So long as compressed gases cannot be stored in cylinders of smaller weight, or chemicals, such as sodium peroxide, used without

producing sufficient heat to set the whole apparatus on fire (as was the case last year with a "pneumatogene apparatus" in Germany), a decrease in the weight of the apparatus cannot be obtained.

A feature in the construction of rescue-apparatus which should always be considered is the means provided for re-

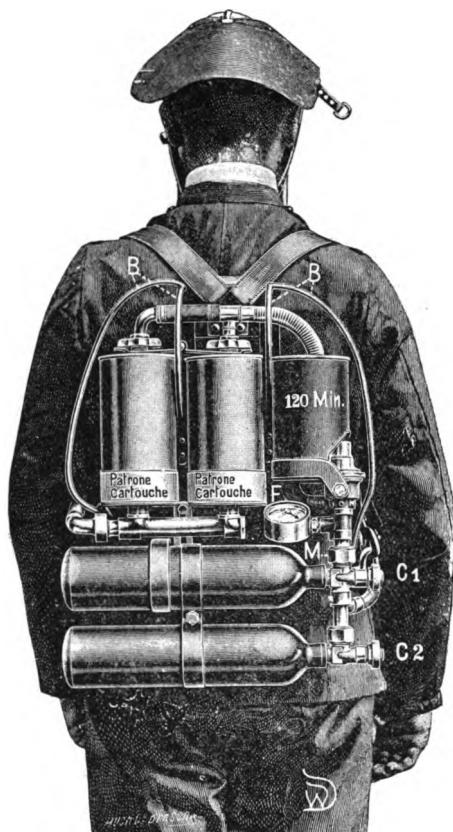


FIG. 2.—THE DRAEGER APPARATUS WITH TWO OXYGEN-CYLINDERS.  
REAR VIEW.

charging. I consider the so-called "potash cartridge" of the Draeger apparatus, which comes packed and sealed, as the best device for doing this work in the shortest possible time, and without any risk of mistake in the quantity of chemicals charged.

Of the helmet or mouth-bag devices adopted by different makers, the Draeger helmet outfit seems to me to be the most perfect, since it enables the wearer to breathe naturally and at

the same time to hear, see, and talk with his fellow-workmen. Personal experience has shown to me the importance of this advantage.

A full equipment of the Draeger apparatus is now kept by the Boston & Montana Consolidated Copper & Silver Mining Co., Butte, Mont., for the purpose of fighting underground fire. After 20 years' experience with all kinds of apparatus,

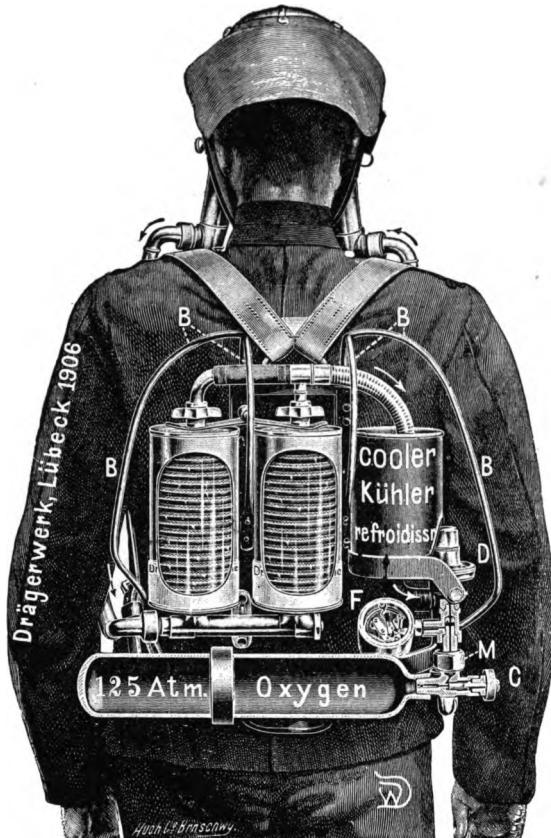


FIG. 3.—THE DRAEGER APPARATUS WITH ONE OXYGEN-CYLINDER.

this company considers the Draeger to be the only one which has given perfect satisfaction. There are about 2,000 Draeger apparatus in use in various countries.

The complete apparatus, ready for use, is shown in Figs. 1 and 2. The main part, which is carried on the back, consists of a frame supporting the cartridge-holder, cooler, pressure-reduction valve, *D*, suction-nozzle, *M*, oxygen cylinders, *C*<sub>1</sub> and *C*<sub>2</sub>,

and pressure-gauge (finimeter), *F*. Steel guard-hoops, *B*, protect the apparatus from injury. Two metal tubes provide communication between the main part and the smoke-mask or res-

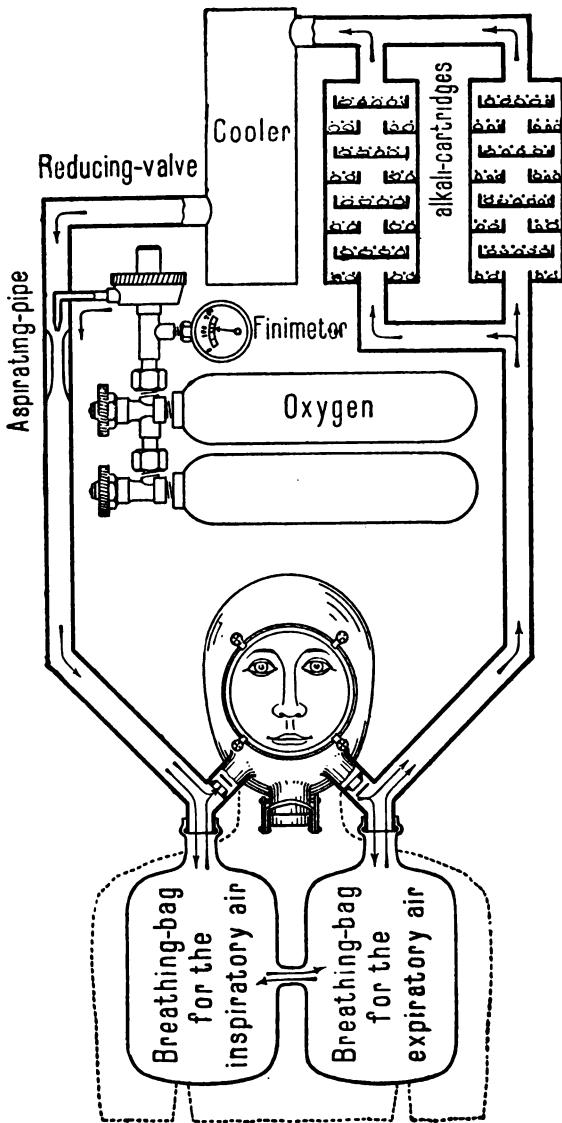


FIG. 4.—DIAGRAMMATIC SKETCH SHOWING THE METHOD OF OPERATION.

piration-bag. The apparatus proper is not soiled by use. The oxygen cylinders can be refilled easily, but the cartridges, after use, are replaced by new ones. Fig. 3 shows a similar appa-

ratus with one cylinder, having parts cut away to illustrate the mechanical construction; the diagrammatic sketch, Fig. 4, outlines the operation. The potash cartridge (marked "Patrone Cartouche" in Fig. 2) contains 20 flat dishes so arranged that the air to be freed from carbonic acid passes successively over each dish. The smoke-helmet, Fig. 5, consists of a pneumatic tube, *L*, shaped to form a tight joint with the head and face of the wearer. It extends from the chin to and around

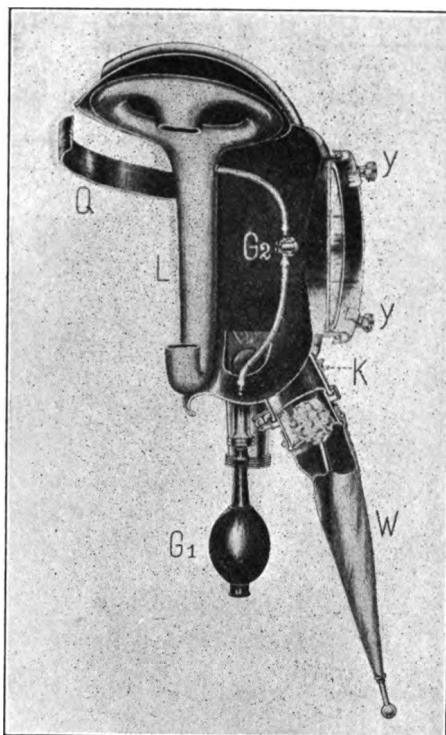


FIG. 5.—DETAILS OF THE HELMET.

the top of the head. It is inflated by means of a rubber air-pump, *G*<sub>1</sub>; a second valve, *G*<sub>2</sub>, on the side of the helmet, being provided to relieve the pressure if the pump is worked too rapidly. A leather strap with a buckle, *Q*, is provided for fastening firmly to the head. The respiration-bags are shown in Fig. 6. The bag at the right hand, *S*, serves as the pure-air reservoir. The air passes through the metal tube in the direction indicated by the arrow into the opening of the screw-

joint, and is drawn in by breathing through the round tube of the helmet. A small mica-plate valve in the tube (not shown in the illustration) allows the air to pass into the helmet, but prevents it from passing back into the supply-tube. The exhaled air passes through a similar tube into the second bag,  $S_2$ , having a mica-plate valve to prevent the air from returning to the helmet through an opening in the screw-joint,  $A$ . The two bags are connected with a channel,  $S_3$ . The exhaled air is drawn through a wide metal tube to the cartridge. At the lower end of the helmet is a wide air-valve,  $K$ , for use while the apparatus is being put on. In this valve is a sponge with

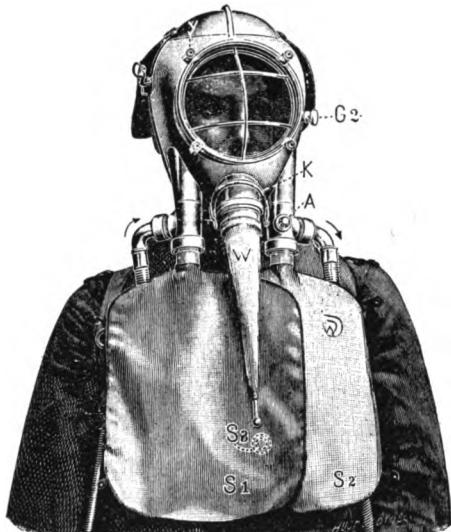


FIG. 6.—DETAILS OF RESPIRATION BAGS.

a projecting handle,  $W$ , which enables the wearer to remove any moisture collecting on the window of the helmet, or to reach the face. The bags are protected by a leather apron, shown in Fig. 1. The window is made of clear plates of mica or of glass, protected by a wire guard. It is held in place by 4 screw-hooks,  $Y$ , and can be easily removed.

Recent terrible mine-fires, explosions, etc., have called fresh attention to the subject of breathing-apparatus by the use of which spaces filled with poisonous gases, such as after-damp, can be traversed with safety for the purposes of exploration or rescue, or for direct fighting against fire.

It is perhaps not so generally known that it is not impossible to resuscitate, by means of pure oxygen, persons who have been suffocated in smoke and after-damp, even when they have remained for more than two hours in these irrespirable gases. The Draeger works, at Lübeck, Germany, make an "oxygen reviving-trunk," which is kept on hand for this purpose at numerous mining rescue-stations throughout Germany. It consists of a cylinder containing oxygen, under very high pressure, connected with an automatic inhaler, and provided with a sufficient supply of pure oxygen for one half-hour's working. The apparatus is again made ready for use by simply putting in a newly-filled cylinder, which enables the work on a suffocated person to be continued for hours.

Persons, even after having been in after-damp for a considerable length of time, may be resuscitated by 10 minutes' treatment with pure oxygen. The official report of the German government mining officials, who investigated the Rheden disaster of Jan. 28, 1907, in which, out of 110 men underground at the time of the explosion, more than 40 were saved by the use of the Draeger rescue-apparatus, mentions that treatment for about 10 min. was required to revive the suffocated.

## The Physical Features and Mining Industry of Peru.

BY GEORGE I. ADAMS, WASHINGTON, D. C.

(New York Meeting, February, 1908.)

### PHYSICAL AND CLIMATIC DIVISIONS.

PERU is divided into three regions—the coast, the sierra, or high mountainous region, and the “*montaña*,” or forest region of the Amazon basin.

*The Coast.*—The coast is an arid region. No rain falls excepting in the extreme northern part, which borders the Gulf of Guayaquil. There is, however, a slight precipitation in the form of mist (*garua*), which occurs on the coast hills during the so-called winter months. The aridity of the coast is due principally to the antarctic or Humboldt ocean-current, which, being cold and having a temperature lower than that of the land, absorbs rather than produces vapors. The coast mists occur during the season when the land is relatively cold. Near the Gulf of Guayaquil the antarctic current diverges from the coast, so that in the Tumbes valley and adjacent country the conditions in the summer months are such as produce rains. In the remaining valleys of the coast, agriculture is made possible only by means of irrigation, and is accordingly very limited in extent, although rich and varied. In the northern and south-central portions of the coast, plains extend inland from the sea, while in the southern part there is a coastal plain separated from the Pacific by a range of coast hills. Between the northern and south-central plains, as well as between the south-central and southern, the foothills of the sierra descend to the seacoast.

*The Sierra.*—The sierra embraces the high land dominated by the lofty cordilleras of the Andes. In the southern part of Peru there are two cordilleras, the western and the eastern, which enter from Chile and Bolivia respectively, and inclose between them the Titicaca Lake basin. To the north of Lake Titicaca these cordilleras unite in the knot of Vilcanota, south of Cuzco. From this knot three cordilleras, known as the western, the central, and the eastern, extend to the northward, reuniting in the

knot of Cerro de Pasco in the central part of the sierra. From Cerro de Pasco three cordilleras diverge. The western extends into Ecuador. The central, after it is cut at the falls of Mans-

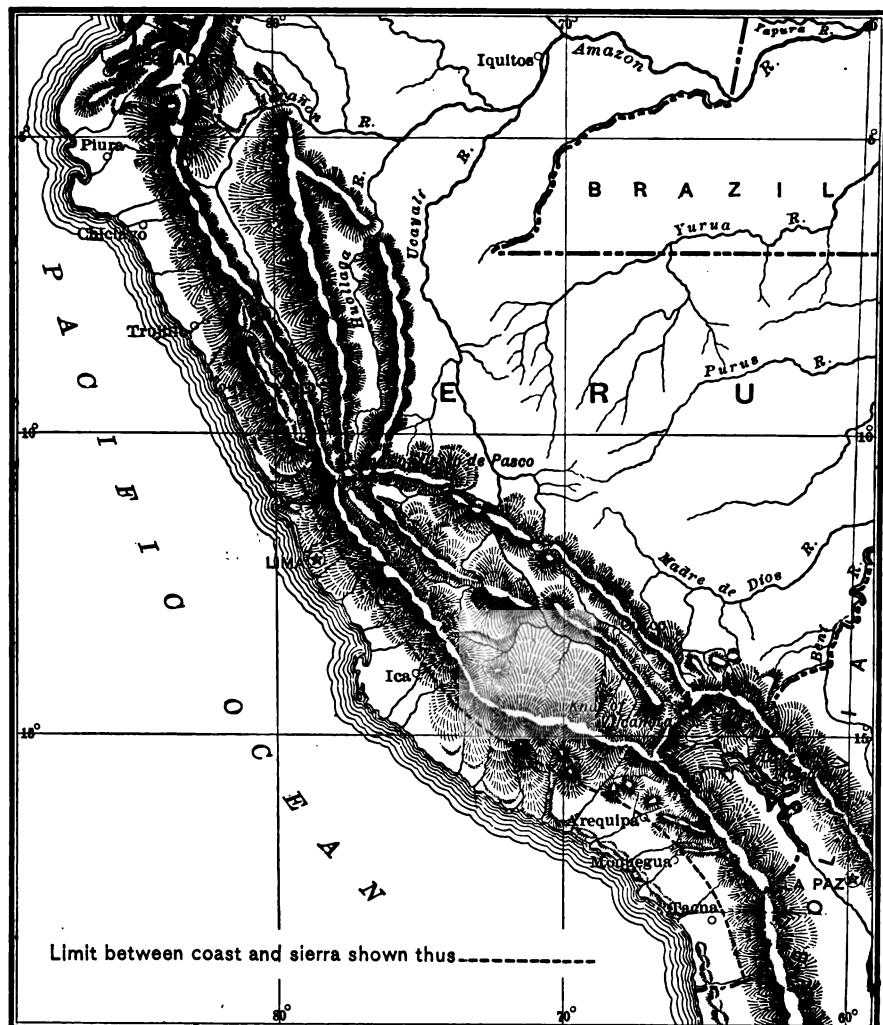


FIG. 1.—MAP OF PERU (NORTHERN AND EASTERN PORTIONS OMITTED), SHOWING THE CORDILLERAS OF THE ANDES.

riche by the Marañon, which is the head of the Amazon, dies out in the plains to the north. The eastern, after it is cut by the Huallaga at the Falls of Aguirre, unites with the central cordillera south of the Marañon. The relations of these cordilleras

are shown in Fig. 1. In the southern part of Peru, where the trend of the mountains changes, producing an irregular curve, there is a high plateau to the west of the western cordillera on

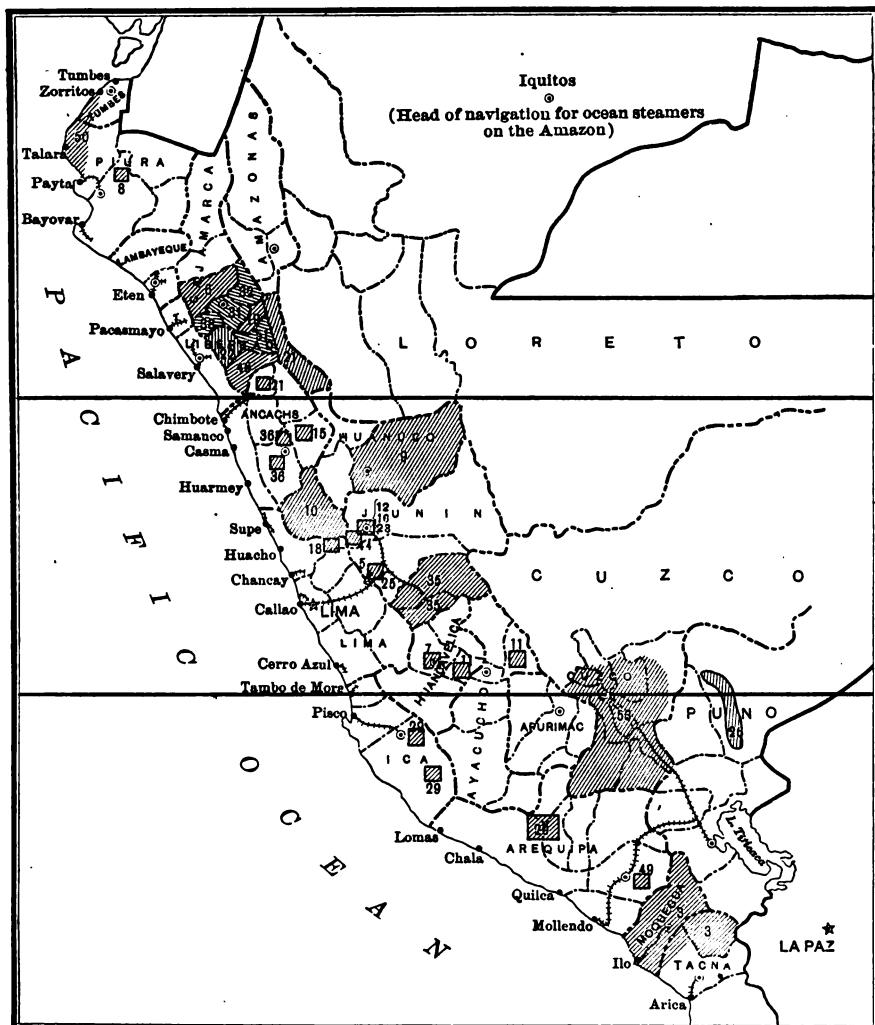


FIG. 2.—INDEX-MAP OF MINING DISTRICTS DESCRIBED IN BULLETINS OF THE CORPS OF ENGINEERS OF MINES OF PERU.

which a chain of volcanic peaks is found, bearing about the same relation to the cordillera as a string does to a bow. The western cordillera, in its northern part, divides for a short distance into two parallel ranges, which re-unite. The eastern is

the main one, known as the White Cordillera, because of its snow-peaks, and the western is called the Black Cordillera.

The western cordillera, which is the continental divide, is a lofty range. In a list of 42 of its passes, one found in the northern part, near Huamachuco, has an elevation of about 6,800 ft. This is the lowest pass, and it will some day be the railway-route from Payta to the Amazon. The highest pass has an elevation of about 15,800 ft., while 27 have elevations exceeding 12,000 ft.

The sierra, especially in its western part, is semi-arid, due to the fact that the moisture brought by the trade-winds over the Amazon valley is nearly all precipitated before crossing the cordilleras, and, moreover, the excessive evaporation due to the altitude causes the moisture of the ground to disappear rapidly. In the summer season there is a moderate rain-fall on the Pacific slope of the western cordillera. This moisture is generally considered to have come over the range from the east. The western limit of these rains is a fairly definite line, seemingly dependent upon elevation and temperature, and corresponds with the limit between the coast and the sierra excepting near the Gulf of Guayaquil, as has been noted above. In the higher parts of the sierra the temperature is too low to permit of agriculture, but products such as barley, potatoes, etc., are grown at moderate elevations and in the valleys of the inter-Andean streams, especially as they flow at lower altitudes in approaching the forest region; the agriculture, although confined to narrow limits, is rich and varied.

*The Montaña.*—The forest region, or *montaña*, as it is called, occupies the Amazon drainage-basin up to the timber-line. There are some grassy plains, but practically the whole is a tropical forest, not yet dominated by man. The main routes of travel are the waterways, and the commerce is largely related to the rubber industry. Iquitos, on the Amazon, is the head of navigation for ocean steamers, but river steamers ply much higher on the principal tributaries.

#### COMMERCIAL FEATURES.

*Ports.*—The principal port of the Peruvian coast is Callao, which is well protected by San Lorenzo Island. There are docks at Callao, which is the only port where cargo can be dis-

charged directly from the steamers, but, inasmuch as the docks are too limited for the commerce, lighters also are used. Piura in the north, Chimbote in the north-central, and Ilo in the southern portions of the coast have well-protected harbors, but, on account of the short piers, lighters are used to carry the cargoes. Many of the remaining ports have long, steel piers reaching out to deep water, to enable lighters to come alongside beyond the limit where the waves usually break with much force. Mollendo is an unprotected port, with wharf piers in a very small basin. In rough weather the swells coming in from the ocean sometimes make loading and unloading from lighters in the unprotected ports impossible. This condition is a serious drawback to commerce. Moreover, the dropping of cargo into lighters necessitates good packing, and secure and heavy boxing and crating to prevent breakage.

*Railways.*—With the exception of the central and southern lines the railways of Peru serve the agricultural rather than the mining industry, since they do not extend beyond the valleys and plains.

The Central Railway, which crosses the western cordillera at an elevation of 15,645 ft., extends from Callao to Oroya, from which place a branch runs south to Huancayo. From Oroya the Cerro de Pasco Railway extends northward to Cerro de Pasco.

The Southern Railway from Mollendo crosses the western cordillera at an elevation of 14,660 ft., and terminates at Lake Titicaca, but from Juliaca, near the lake, a branch extends to the north, reaching nearly to Cuzco, to which place it is being extended. The commerce on Lake Titicaca, which is principally with Bolivia, is carried on by small steamers. A coast railway which is now being extended is the one from Chimbote into the rich mineral districts of the department of Ancachs. The government is stimulating railroad-building by granting subsidies and concessions. The most important of these projects is a railway to connect with the Central in the sierra near Cerro de Pasco, and to extend to the navigable waters of the Ucayali, a tributary of the Amazon. Provision is also made for building an extension of this line to the coast to the north of the Central Railway. In the south of Peru the railway from Ilo to Moquegua is to be rebuilt, and a branch from the Southern Railway to Ilo is contemplated in order to provide a good port as a ter-

minus for that line. The prolongation of the road which now runs from Payta to Piura is the project which will give Peru a northern railway, and one connecting with the head of navigation on the Amazon.

Extension of the coast railways in general into the sierra is contemplated, and is essential to the development of the mineral resources.

In the sierra the routes of travel are usually little better than mountain trails, and the difficulty of taking in machinery and bringing out metals by pack-trains is the principal drawback to the mining industry.

*The Mining Districts.*—Nearly all of the important mining localities are in the sierra. The conspicuous exceptions are the petroleum-deposits and sulphur-mines in the northern coastal plains, and the gold-bearing quartz and placer-gravel deposits in the border of the forest region in the southern part of the country. The high altitude affects those not accustomed to the sierra, and it is usual for skilled and technical employees to take vacation trips to the coast.

*Official Lists of Mining Claims.*—The *Padron de Minas*, published May 31 and Nov. 30 of each year, contains a list of mines with a statement of the annual taxes paid or due. In the *Padron* published at the end of 1906, there were 9,789 claims listed, of which, according to the statement in the *Mineral Statistics* for that year, about 1,200 were being exploited by 160 companies.

TABLE I.—*Mineral Production of Peru for 1906.*<sup>1</sup>

|                             |                     |                |
|-----------------------------|---------------------|----------------|
| Coal, . . . . .             | Metric tons, 79,969 | Libra, 138,155 |
| Petroleum, crude, . . . . . | 70,832              | 242,542        |
| Gold, . . . . .             | kg., 1,247          | 170,355        |
| Silver, . . . . .           | Metric tons, 230    | 972,958        |
| Copper, . . . . .           | Metric tons, 13,474 | 996,055        |
| Lead, . . . . .             | Metric tons, 2,568  | 35,125         |
| Bismuth, . . . . .          |                     |                |
| Nickel, . . . . .           |                     |                |
| Mercury, . . . . .          | kg., 2,304          | 495            |
| Salt, . . . . .             | Metric tons, 20,226 | 20,226         |
| Borax, . . . . .            | Metric tons, 2,598  | 23,392         |
| Sulphur, . . . . .          | Metric tons, 1,830  | 2,745          |
| Antimony, . . . . .         | Metric tons, 91     | 8,526          |

NOTE.—The Peruvian gold *libra* is made by law to maintain a parity with the English pound sterling. Ten silver *soles* equal one *libra*, regardless of any fluctuation in the price of silver bullion. One hundred *centavos* equal one *sol*.

<sup>1</sup> *Bulletin No. 54, Cuerpo de Ingenieros de Minas*, by German Klinge.

*Mineral Production.*—The mineral production during the year 1906 is shown in Table I. The coal was produced and used chiefly in the Cerro de Pasco district. The petroleum was produced at Negritos, Zorritos, and Lobitos, the refineries being at the first two places named. The principal production of gold was from the mines of the Inca Mining Co., at Santa Domingo, in southern Peru, within the border of the forest region north of Lake Titicaca. The silver production was principally from the Departments of Junin, Lima, Huancavelica, Ancachs, and Cajamarca, in order of importance. About half of the copper was produced from Cerro de Pasco and one-fifth from Yauli (Morococha), in the Department of Junin, and most of the lead was from the same districts.

*Metallurgical Plants.*—According to the *Mineral Statistics* for 1906, the following establishments were in operation during that year :

|   |    |
|---|----|
| Smelting and bessemerizing of copper, . . . . .             | 2  |
| Smelters producing matte, . . . . .                         | 13 |
| Lead-smelters, . . . . .                                    | 3  |
| Lixiviation, . . . . .                                      | 24 |
| Amalgamation, . . . . .                                     | 17 |
| Cyaniding, . . . . .  | 2  |
| Concentrating-plants not connected with smelters, . . . . . | 3  |
| Petroleum refineries, . . . . .                             | 2  |
| Sulphur refinery, . . . . .                                 | 1  |

Of the smelting-plants, the more important are the smelters of the Cerro de Pasco Mining Co., having a capacity of 500 tons per day, situated near Cerro de Pasco; the Backus and Johnson smelter at Casapalca, having a capacity of 150 tons per day; the Huaracaca smelter, near Cerro de Pasco, having (with concentration and amalgamation) a capacity of 100 tons per day. These, together with some smaller plants, are on the Central Railway of Peru. Outside of this group the small smelters which were in operation are situated away from railroad facilities. The construction of some small smelters was begun during the year.

*Labor.*—The labor in the mines is performed by Indians and the mixed native race. They are patient and docile workmen, their principal defects being their lack of education in anything excepting Spanish methods, and their custom of celebrating

feast days. Many of them have small patches of land which they cultivate, and, as a result, cannot be relied upon for constant work. In some localities the Indians do not speak Spanish and must be directed by men who know the Indian languages. Usually, where mining operations are carried on constantly, and the rate of pay is good, the Indians become accustomed to depend upon the mines for their living, and many of them become capable workmen. In the work connected with mining the daily pay of a common laborer ranges from 20 *centavos* to one *sol*, while in the smelting- and concentration-plants it ranges from 60 *centavos* to 1 *sol* 20 *centavos*. Packing ore costs from 40 to 50 *centavos* for a ton per kilometer. These figures are from the *Mineral Statistics of Peru* for 1906.

*Maps.*—The mother map of Peru is the one made by Raimondi on a scale of  $1:500,000$ , and published in sheets for convenience in handling. The sheets are on sale in Lima at reasonable prices, excepting a few which are rare or out of print. These maps contain many inaccuracies, but are the best and, in fact, the only ones which can be obtained, excepting those contained in the *Bulletins* of the Corps of Mining Engineers.

*Literature.*—There are many scattered references to the mines of Peru, but most of them are out of date, and many are not obtainable. The *Bulletins* of the Corps of Engineers of Mines of Peru are the most readily available, being published for free distribution, and they have all been issued since 1903. They are in Spanish, and not always concise or clearly summarized. For the most part they are in the form of reconnaissance reports. Some of them have been written by inexperienced young graduates from the School of Mines at Lima, but they contain important data, and usually are accompanied by small maps which show the routes to the districts.

In order to give an idea of the portions of the country covered by these reports, Fig. 2 shows the positions of the areas discussed in the *Bulletins*. In dividing the general map of the country into three parts, consideration was given to the fact that these divisions will always be more or less distinct, because of the physical features, ports, and routes of travel. Most of the forest region has no mining developments, and only a small part of it is included.

The following list of *Bulletins*, each of which is supplemented

with a few explanatory notes, comprises only those of the series which relate to the mining industry.

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##### *Bulletins Pertaining to the Districts on the Northern Part of the Index-Map, Fig. 2.*

Bulletin No. 6. Mineral Resources of the Province of Hualgayoc, by F. Malaga Santolalla, 1904. Production of 40,000 marcos of silver on an average for each of the preceding 13 years. Lixiviation introduced in 1890. Nine lixiviation-plants enumerated. Also copper, lead, gold, and workable anthracite coal.

Bulletin No. 8. Iron-Deposits of Tambo Grande, by Pedro C. Venturo, 1904. Not developed; no coal near.

Bulletin No. 19. The Province of Cajabamba and Its Mineral Districts, by F. Malaga Santolalla, 1905. Copper, gold, silver, lead. One lixiviation-plant and one smelter.

Bulletin No. 21. Mineral Resources and National Importance of the Province of Pataz, by Felipe de Lucio, 1905. Gold-mines and placers; small production. Annex: Coal-deposits of Ancos in Province of Pallasca. Anthracite exploitable.

Bulletin No. 22. The Province of Otuzco and Its Mineral Districts, by F. Malaga Santolalla, 1905. Copper, silver, lead, with gold values; small production; one lixiviation-plant.

Bulletin No. 31. Importance of the Province of Cajamarca from a Mining Standpoint, by F. Malaga Santolalla, 1905. Copper, lead, silver, gold, antimony, sulphur, and coal. Concentration and lixiviation. Important deposits; small production.

Bulletin No. 32. Metalliferous and Coal-Deposits of the Province of Celendin, by F. Malaga Santolalla, 1905. Copper, silver, lead, gold, and coal.

Bulletin No. 38. The Province of Contumaza and Its Mineral Districts, by F. Malaga Santolalla, 1906. Copper, lead, zinc, antimony, and coal. At present of little promise, excepting possibly the coal.

Bulletin No. 46. Mineral Resources of the Province of Santiago de Chuco, by F. Malaga Santolalla, 1906. Silver, copper, and coal. Eight lixiviation-plants; moderate activity in mining. A promising district. Need of establishing smelting-operations.

Bulletin No. 50. Preliminary Report on the Petroleum Field of Northern Peru, by V. M. Masters; in press.

Bulletin No. 51. Report on Mining Industry of the Province of Huamachuco, by F. Malaga Santolalla, 1907. Copper, silver, lead, antimony, and coal. One lixiviation-plant; small production.

##### *Bulletins Pertaining to the Districts on the Central Part of the Index-Map, Fig. 2.*

Bulletin No. 5. Report on Work Done (by Commission) in the Mineral District of Yauli (Morococha), by M. G. Masias, 1903. Enumerates silver- and copper-mines, of which nine are in exploitation.

Bulletin No. 9. Mineral Resources of the Province of Huanuco, by Nicanor G. Ochoa, 1904. No producing mines; formerly small exploitation.

Bulletin No. 10. The Mineral District of Cajatambo, by F. Malaga Santolalla, 1904. Gold, copper, lead, silver, manganese, and workable coal. Now, three lixiviation-plants, and one small smelter is being built.

Bulletin No. 12. Geological Observations from Lima to Chanchamayo, by Gustav Steinmann, 1904. General mining geology of Cerro de Pasco district.

Bulletin No. 15. Mineral Resources of the Districts of Chacas and San Luis, by Enrique I. Dueñas, 1904. Silver, lead-production; coal-deposits. Now, one smelter and two lixiviation-plants.

Bulletin No. 16. Report of the Commission of Cerro de Pasco, 1904. "Smelters in Cerro de Pasco," by Carlos E. Velarde. Nine reverberatories and one water-jacket. Cerro de Pasco Mining Company's smelter in construction, now producing. Production in year, 4,070 metric tons of copper and 7,648 kg. of silver.

"Inversion of Capital in Cerro de Pasco," by M. A. Denegri. A short history of the district and a discussion of the mineral deposits and coal-fields. Also published in *Mining World* (Chicago), vol. xxi., No. 4, p. 77 (July 23, 1904).

Bulletin No. 18. Coal-Deposits of the District of Checas, by E. A. V. de Habich, 1904. Good quality of workable anthracite.

Bulletin No. 25. Present Status of the Mining Industry in Morococha, by M. G. Masias, 1905. Copper, lead, silver. Three smelters and three concentrating-plants. One of the principal mining centers of Peru.

Bulletin No. 35. Mineral Resources of the Provinces of Jauja and Huancayo, by Enrique I. Dueñas, 1906. Copper, silver, lead, molybdenum, coal, and asphaltite; small production. Developing because of extension of railway to Huancayo.

Bulletin No. 36. Iron-Deposits of Aija and Calleycancha, by Luis Pflücker, 1906. Not exploited. Also references and data concerning mines in same region.

Bulletin No. 44. The Mineral District of Huancavelica (or Huailay) in the Province of Cerro de Pasco, by Carlos E. Velarde, 1906. Copper and silver, coal near by. One small smelter and another building.

*Bulletins Pertaining to the Districts on the Southern Part of the Index-Map, Fig. 2.*

Bulletin No. 3. Report on the Coast Provinces of Moquegua and the Department of Tacna, by F. Alayza y Paz Soldan, 1903. Copper-mines and rock-salt in coast range near Ilo; copper, lead, silver, and coal in sierra; also sulphur and borax; very small production.

Bulletin No. 7. Quicksilver of Huancavelica, by A. F. Umlauff, 1904. Extensive old mines now abandoned would form basis of new industry.

Bulletin No. 11. Deposits of Tungsten at Lircay and Nickel at Rapi, by E. A. V. de Habich, 1904. Have been exploited on small scale.

Bulletin No. 20. The Gold-Deposits of Condesuyos and Camana, by L. U. Alvarado, 1905. Quartz-veins exploited on a small scale.

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Bulletin No. 49. Borax-Deposits of Laguna de Salinas, by Alberto Jochamowitz, 1907. Moderate exploitation.

Bulletin No. 53. Mining Aspect in the Department of Cuzco, by Enrique I. Dueñas, 1907. Copper-, silver-, lead-, and gold-prospects; also auriferous gravels; no production. Refers to newly-discovered petroleum field at Pusi, on border of Lake Titicaca.

## The Hardinge Conical Pebble-Mill.

BY H. W. HARDINGE, NEW YORK, N. Y.

(Birmingham Meeting, October, 1908.)

DISREGARDING for the present the economic side of a new device, let us turn to that feature of the conical pebble-mill which is of interest from a scientific point of view, and consider the device as a puzzle in which the theories of the cylindrical type of mill have been increased.

Many articles have been written on the theory of the tube-mill, and explanations have been made which do not explain; but these have evolved suggestions of practice which have resulted in changes in the tube as to length, diameter, feed, discharge, speed of rotation, rotation on hollow trunnions, rotation on rings, and changes in the operation as to quantity and size of pebbles, charge of load above or below the axis, crushing by causing the larger pieces of the material of the charge to act as grinders, etc.

The practical worker in crushing is first interested in the endeavor to reach an economic means of accomplishing a desired end; but the improvements in crushing-practice have been largely left to the manufacturer of machinery, who, as a rule, has little, if any, knowledge of the specific requirements—such as sizing for concentration without pulverizing the metals, instead of pulverizing the rock or gangue; the metals being the more friable, while the rock is tough and not so easily disintegrated. A reversal of this practice is the aim of sliming direct for cyanidation.

In the ordinary cylindrical mill, having a diameter of 4 or 5 ft. and a length of from 15 to 27 ft., it has been found that the maximum size of the particles of the charge must not exceed 1 mm. (about 25 mesh), some of which, upon entering the mill, is immediately reduced to a slime. The work upon the individual particle having been finished, it should be passed out of the mill; but, instead of this, the finely comminuted material

is retained in the tube until it works its way through 20 ft. or more of the mill, interfering with subsequent work, and absorbing energy by acting as a springy compressible medium between the pebbles.

In ordinary practice, both ends of the cylinder or tube are loaded with the same quantity and sizes of pebbles, and when these are reduced in size through gradual wear, the larger pebbles expend a further amount of power in acting upon the smaller ones, as well as in regrounding particles already sufficiently reduced in size, which should be ground by the smaller pebbles—for the much advocated “angle of nip” applies to a pebble as well as to a roll—or if the action within the tube-mill is not one of rotative crushing, it is at least using the same medium to crush the 0.5 mm. size and the 1 mm. size—a system as abusive of economy of power as using a sledge-hammer to drive tacks as well as spikes. The work is performed in both cases, but in the latter it is accomplished only at a great waste of energy, as well as a nullification of the desired effects, by carrying the work to an undesirable point.

The tube-mill of the past few years, like the action of the sledge-hammer upon the tack, has been accepted because it has filled a long-felt want, and has performed work more efficiently than the still more wasteful stamp for fine grinding. It has, however, not only done its work, but over-done it, by using a 3-in. pebble to crush 25-mesh sand-particles, having a relation of mass of 1 : 238,000, and then using the same power and crushing-medium to crush 60-mesh material in which the relation is 1 : 2,700,000, or more than ten times that of the first case.

In order to correct this enormous waste of energy, as well as to approach more nearly the desired results, a pebble-mill of odd form has been designed which utilizes principles of physics to attain maximum results for the energy expended, and control of the size without regard to gravity. While it cannot be said that this form of conical mill has carried these results to a finality, a great stride has been made in that direction, as is shown by a study of Fig. 1, which presents the comparative peripheral speeds per minute at different sections of the mill, and a diagrammatic comparison of the size and weight of the crushing-pebbles and the particles to be crushed. The great

increase in the difference as the sizes decrease is comparatively equalized by the diminished fall and reduced peripheral speed.

The discovery of this special shape of mill arose from experiments necessitated by excessive cost of crushing. I refer to the gradual sizing-effect, not only of the material crushed, but of the crushing bodies as well, for it is found that, aside from the crushing caused by the greater fall of the pebbles of larger diameter in the zone of greatest speed, the next smaller pebbles, through a sizing-action, due to two or three different

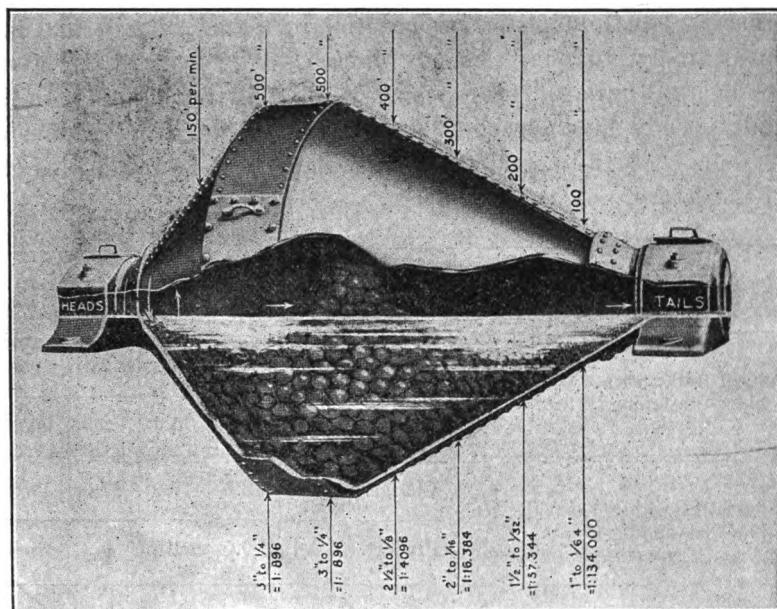


FIG. 1.—THE HARDINGE MILL, SHOWING COMPARATIVE PERIPHERAL SPEED PER MINUTE AT DIFFERENT SECTIONS, AND COMPARATIVE SIZE AND WEIGHT OF CRUSHING-PEBBLE AND PARTICLE TO BE CRUSHED.

causes, take a place up the incline of the outlet end of the mill, and act upon relatively smaller sizes of particles to be crushed. While this sizing is apparent to the eye, the chief cause resolves itself into a scientific puzzle. My engineering friends have attributed this sizing-action to no less than ten different causes. In one instance only has the main or fundamental principle been explained.

If any one takes an interest in this subject, from either an economic or a scientific standpoint, let him take two ordinary

glass laboratory-funnels, from 5 to 7 in. in diameter, preferably ribbed on the inside; place them base to base, first partly filling one with dry sand, ranging in size from fine particles to coarse gravel; hold these funnels together with adhesive tape or paper labels; revolve at a slight angle from the horizontal, and observe the results. An opinion will doubtless be formed immediately as to the cause of the astonishing results, but, upon further observation, this opinion will probably be changed two or three times before a satisfactory conclusion is reached.

The following comparison of actual results, obtained by crushing equal quantities of material in a conical mill and in an ordinary tube-mill, is of interest. The charge for the conical mill was of 4-mesh size, while that for the tube-mill had already been crushed and passed through a 25-mesh screen. A 0.25-in. grain contains more than 200 particles of 25-mesh size.

|  |          | On 40-Mesh Screen. | On 60-Mesh Screen. | On 80-Mesh Screen. | On 100-Mesh Screen. | Thro' 100-Mesh Screen. |
|--|----------|--------------------|--------------------|--------------------|---------------------|------------------------|
|  | Charge.  | Per Ct. 75.5       | Per Ct. 6.6        | Per Ct. 5.5        | Per Ct. 2.3         | Per Ct. 9.5            |
|  | Product. | 0.0                | 1                  | 5.4                | 2.5                 | 90.8                   |
| Conical mill ; with .2,000 lb. pebbles ; consuming 15 h.p. | Charge.  | 1.5                | 13.5               | 17.0               | 17.0                | 53.0                   |
| Conical mill ; with .2,000 lb. pebbles ; consuming 15 h.p. | Product. | 0.0                | 0.5                | 1.5                | 0.2                 | 96.5                   |
| Tube-mill ; with 11,000 lb. pebbles ; consuming 48 h.p.    | Charge.  |                    |                    |                    |                     |                        |
| Tube-mill ; with 11,000 lb. pebbles ; consuming 48 h.p.    | Product. |                    |                    |                    |                     |                        |

A study of Fig. 1 will help to explain the astonishing results given by the conical mill.

The total weight of a conical mill (except the lining), having a capacity of from 2 to 4 tons of material per hour, is 8,500 lb., and the floor-space occupied is 7 by 10 ft. The charge of pebbles weighs about 2,000 lb., and the power required for operation is from 12 to 15 h.p. These mills can be arranged singly, in series or in tandem, and the large amount of aëration which takes place during the crushing suggests promising results in cyaniding ores during crushing, which, if attained, will greatly simplify present milling-practice.

A full-sized conical mill has recently been erected near New York City for the purpose of conducting crushing-tests on a

large scale, and with certain ores the results have far exceeded the most sanguine expectations. A test on magnetite ore from Pennsylvania gave the following:

|                        | On<br>0.25-in.<br>Screen.<br>Per Cent. | On 20-<br>Mesh<br>Screen.<br>Per Cent. | On 40-<br>Mesh<br>Screen.<br>Per Cent. | On 60-<br>Mesh<br>Screen.<br>Per Cent. | On 80-<br>Mesh<br>Screen.<br>Per Cent. | Through<br>80-Mesh<br>Screen.<br>Per Cent. |
|------------------------|--|--|--|--|--|--|
| Size of ore fed, . . . | 53.2                                   | 30                                     | 2.2                                    | 2.2                                    | 1.6                                    | 10.9                                       |
| Size of product, . . . | 0.0                                    | 0.3                                    | 0.6                                    | 1.2                                    | 2.5                                    | 95.0                                       |

The ore fed to the mill was "run of mine," which was first shoveled by a coke-fork having tines spaced 1 in. apart, the coarse material being rejected, so that the undersize was 1 in. and finer. The mill contained 2,000 lb. of 2- and 3-in. pebbles. The ore was crushed to 80-mesh size at the rate of 4 tons per hour at an expenditure of 17 h.p. This type of mill appears to be specially adapted to the use of lumps of ore instead of the usual foreign bodies for grinding. In a separate test on Pennsylvania magnetite, pieces as large as 8 in. in diameter were fed to the mill and the charge was ground at the rate of about 2 tons per hour, the product being reduced to a fineness corresponding to the results obtained in the first test on magnetite mentioned above.

Whether a mill of this character, or, in fact, any fine grinder can be adjusted for fine or for coarse grinding appears to be an open question, but the following data, obtained in actual practice, show that the conical mill possesses this qualification.

For fine grinding, a 6-ft. conical mill recently installed at the plant of the Enterprise Mining Co., Cooney, N. M., for fine-grinding gold-ores prior to treatment by the cyanide process, is reported by C. F. Long, President of the company, to be very satisfactory, as to both capacity and small amount of power required.<sup>1</sup>

For comparatively coarse crushing, the conical mill in operation at the sapphire-mines of the American Sapphire Co., in Yogo county, Mont., is reported by John T. Morrow,<sup>2</sup> the President of the company, to give excellent results. This mill has a crushing capacity of from 5 to 8 tons of material per hour. The interior surfaces of the cones are covered with a

<sup>1</sup> Private communication to the author, Feb. 26, 1908.

<sup>2</sup> Private communication to the author, May 28, 1908.

series of angle-irons placed longitudinally, and soon after the charge is made and rotation begun, the spaces between these irons become filled with pieces of the material to be crushed, thus forming a protective lining for the mill. A special feature of the operation is the control of the size of the crushed material passing out from the mill, which can be made to vary from the finest slime to pieces  $\frac{1}{8}$  in. in diameter.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

## The Mineral Resources of Korea.

BY HALLET R. ROBBINS, A.B., B.Sc., LONDON.

(Birmingham Meeting, October, 1908.)

KOREA, the ancient "Hermit Kingdom," is a peninsula jutting out from the coast of eastern Asia. By the natives it is called "Chosen," which, translated, means "Land of the Morning Calm." It lies between the Yellow sea and the Sea of Japan. On the north it is separated from Manchuria and the Russian province of Primorsk by the Yalu and Tiumen rivers; on the south the Korean straits interpose a rough voyage of 120 miles to the nearest point in Japan. The entire country is situated between the parallels of 34° and 42° N. latitude.

The surface of the country is made up of successive ranges of unglaciated mountains, separated by narrow, fertile, and more or less densely populated, valleys.

Through all the obscure centuries of its history, Korea has succeeded in maintaining a monastic seclusion, over which, from time immemorial until the late Chino-Japanese war in 1894, China exercised a shadowy sovereignty.

Although Korea had been forced into slight foreign contact previously, her first foreign treaty was signed with Japan in 1876.

Under the restraining guardianship of China, the Japanese treaty bore but insignificant innovations for Korea; but when, in 1883, a treaty was made with the United States, the first of the western nations, a decade after the American gunboats, under Commodore Rodgers and Lieutenant Schley, forced their way up the Salee river, shooting daylight through the ancient walls and fastnesses, Korea awoke from her sleep of 4,000 years.

The Korean peninsula suddenly became the arena where rival nations' enterprises and individuals met in fiercest conflict. Out of this struggle grew two singularly successful American

enterprises, both of which have played an important part in developing the natural resources of the country.

The first, and best known of these, is the Oriental Consolidated Mining Co., which was organized by Mr. Leigh Hunt (well known in connection with cotton and irrigation enterprises in the Soudan), with the co-operation of Mr. W. D. Townsend, of Chemulpo. Mr. Townsend was one of the first white men to travel in the interior of Korea, and the very first to visit the mines in the Unsan district. Dr. H. N. Allen, then American minister, being on very friendly terms with the Emperor, secured for these Americans a concession for all mineral and timber lands in that district, which is about a day's journey NNE. of the town of Anju, and about 100 miles north of the city of Pingyang. The area of the concession is not accurately known, never having been surveyed; but it is approximately 275 sq. miles. Within this area are 10 separate gold-mines, of varying size and richness, as well as some deposits of very low-grade auriferous gravel. The work of this company began at the Chittabalbie mine with a 10-stamp mill, operating on \$50 rock. This mine is now completely exhausted, after producing \$1,500,000 worth of bullion. Other mines have been and are now being opened from time to time in different parts of the concession; and there are to-day 5 or 6 producing mines, two of which, Taracol and Tabowie, are equipped with 80-stamp mills. At Taracol there is also a cyanide-plant for treating the concentrates from the mill. This camp, the largest on the concession, contains blacksmith-, machine-, and carpenter-shops, store-houses, a bunk-house, "chow-house," etc. A view of the camp is given in Fig. 1.

The total amount of bullion produced to date is about \$9,500,000, and the net profit to the company has been considerably over \$250,000 per year, which represents a very large percentage on the capital actually invested in plant and equipment. The value of the ore now worked averages about \$5 per ton. At the Taracol mine this is about one-half free-milling, and about 81 per cent. of the remainder is extracted by leaching with potassium cyanide solution in the ordinary manner. The labor question has afforded some perplexities in the past, but, on the whole, has been comparatively simple. Koreans make excellent underground miners, and are used

exclusively for this purpose. All mining is done by hand. For ordinary unskilled labor on the surface, and for certain kinds of skilled labor, the Chinese have proved themselves greatly superior to the Koreans. These Chinese come largely from Shantung, the province from which most of the Rand contract-coolies were recruited. They are very industrious and easy to handle. The rate of wages for Korean miners and Chinese coolies is about 23 cents per day of 10 hr. As to skilled labor, Japanese carpenters receive about \$1.50 per day. Chinese machinists, engineers, bricklayers and stone-cutters are obtained at considerably lower prices. Ore is mined for from 75 cents to \$1.50 per ton, depending on local conditions at the different mines. The cost of milling is about 58 cents, nearly half of which is cost of fuel. The cost of cyaniding at the Taracol plant is slightly over \$2 per ton of mixed concentrates and heavy sands. These low costs appear to be due largely to the cheapness and efficiency of the native and Chinese labor, and to the competency and faithfulness of the white shift-bosses and foremen.

The main sources of loss are inadequate protection against fire, inefficient metallurgical treatment, and the numerous changes in the corps of white employees, of whom there are from 60 to 75. A large dam was constructed to impound water for power; but, owing to some flaw in the design, an insufficient wasteway was provided, and just as the dam was nearing completion, the seasonal rains came on and washed it away. Its replacement was a heavy burden of expense, and the method of construction, that of hand-packed rock-fill with a timber apron, does not seem to have been the most economical for this location, where conditions were favorable to a loose rock-fill dam with a concrete core, or even to an earth dam with core or puddled wall.

However, the enterprise has proved very profitable since its inception, although the future prospects are hardly as encouraging as might be wished. Coal is not available for fuel, and the company is obliged to depend on local woodland for cord-wood and mining-timbers. They have cut practically all the trees from the area of their concession, or at least in the vicinity of the mines.

The other great American enterprise in Korea is that of

**Messrs. Collbran & Bostwick.** Originally railway and general contractors, they have extended the sphere of their activities over a wide field. They built the first railroad in Korea, the Seoul-Chemulpo line, 26 miles long, which crosses the Han river by a steel through-truss bridge of 9 spans. This line was well constructed and of standard gauge; and so well did it please the Japanese that they bought it, and built the rest of their extensive Korean railroad system to match it. One may to-day ride through the entire length of Korea over as good a roadbed, and in cars as comfortable, as on any standard American railroad, while in Japan the trains are narrow gauge and built after the English pattern, so that they impress the traveler more as toys than anything else. A view of Chemulpo harbor is given in Fig. 2.

The same firm built and now operates an electric street-railway in Seoul, which gives the 250,000 inhabitants excellent service to all parts of the city and suburbs at a very moderate fare. An interesting photograph of one of these cars is given in Fig. 3. The cars are well patronized by the natives, and the system yields a large revenue. Electric light and power are supplied to private consumers about the city, including the residences of foreigners, foreign hotels, foreign consulates, Korean government buildings, etc. Moreover, the construction of a complete water-works system for the same city has just been completed by the firm. This system will supply all quarters of the city with an abundance of pure water. The water-supply of the city has, heretofore, been derived from shallow wells, which were all contaminated by seepage from the neighboring open sewers; and epidemics of water-borne diseases have been of annual occurrence. The water was conveyed from the wells to the houses of consumers by carriers, each bearing two wooden buckets or coal-oil tins suspended from a framework on his back. They used no sanitary precautions in handling the water, and every opportunity for contamination from dust, etc., was afforded.

**Messrs. Collbran & Bostwick** conduct also a large banking business, supplying capital to native and Chinese merchants and others. Such borrowers prefer to deal with the American, rather than with the Japanese, bank.

By no means the least important of the firm's activities are

its mining interests. They have already done some work in the development of a gold-mine at Suan, about 60 miles E. of Pingyang, in which there is now in sight a considerable body of “\$12” ore. Conditions here are favorable for economical operation, and plans are under consideration for the erection of a stamp-mill at this mine during the coming summer. The firm is also interested in a copper-mine in the north-central part of Korea, which is very favorably situated for economical operation, except for the matter of transportation—being five days’ journey over a rather rough trail from the coast at Puk-Chun. It is, however, in the center of the only extensive forest-area in Korea; and an abundant supply of charcoal and mining-timber is thus assured. Considerable work has been done here by native Koreans, who mine the ore with hammer and gad, roasting it in crude stalls built of stones. Their smelting-operations are somewhat interesting. Charcoal only is used as fuel, and the blast is produced by four coolies, two on each end of a sort of piston-rod which projects from each end of a rectangular wooden box, about 18 in. wide, 3 ft. high, and 5 ft. long, with flap-valves made of stiff paper or cardboard in each end. A wooden piston moves back and forth in the box as the men push and pull on the rod, and a blast of surprising pressure and steadiness is produced. Their smelting-furnaces are difficult to describe. In general, they resemble a blacksmith’s forge.

The work of the natives has developed a promising body of pyritic ore, assaying about 12 per cent. copper, and carrying appreciable values of gold and silver. Water-power may easily be secured in the neighborhood, since the rainfall is abundant, and the streams have a rapid fall toward the Yalu river. Development is to be started at this mine as soon as certain questions regarding the terms of the concession have been adjusted.

This mine is in the center of the tiger district of Korea. It is not generally known that real “life-sized” tigers inhabit such cold climates as that of Korea and Manchuria, but it is a fact that tigers as large and ferocious as those of the Bengali jungles are found in these regions. While I was stopping at this copper-mine, I was awakened, in the dead of night, by a tremendous commotion outside my door. Natives were

shouting, Japanese soldiers were firing their rifles and revolvers, and a crimson glow lighted up the surroundings. Asking from my interpreter the cause of the excitement, I was informed that five tigers had been observed prowling about the outskirts of the village, and that the noise and fire had been created with the view of scaring them away. Next morning we learned that the fresh-picked bones of three Korean wayfarers had been found not far away. I have seen tiger-tracks measuring about 5 in. in diameter; and I always carried my Smith & Wesson "44" ready for prompt use if required. Tiger-hunting is a favorite sport among the more adventurous Koreans, as a tiger-skin will bring from \$50 to \$100, upon which a native may live for a year in idleness and luxury.

Fig. 4 is a view of the mining-camp at Kojimdong, and Fig. 5 shows the crude method of roasting the ore in stalls.

Several other foreign mining enterprises, established in Korea, have met with varying degrees of success or failure. An English company secured a concession for a very promising gold-mine at Gwendoline, near Pingyang, but were deceived by the erratic form of the ore-body into investing a very large sum of money in plant and underground prospecting. The deposit suddenly pinched out at a comparatively shallow depth, with the result that the company suffered a net loss of nearly 1,000,000 yen (\$500,000).

A German firm secured a concession for some placer ground in the province of Kang-won, but their operations were conducted at a considerable loss. Report has it that crafty natives salted the samples taken by the company's engineers before the concession was taken.

An Italian syndicate has a concession for some gold-prospects near Sen-chun in the province of Pyong-an, but, at last accounts, active work had not begun. At one of these prospects I saw a very clever piece of native workmanship. It was a little stamp-mill, driven by an overshot water-wheel, complete in every respect, but, with the exception of the shoes and dies, made entirely of wood. Three stamps were dropping and crushing ore in a slow but effectual manner. Mercury was not used to amalgamate the free gold; but the pulp as it came from the mortar was panned by hand. No statistics were available

as to the duty of the mill, or assay-values of the heads and tails; but it did not seem probable that a large profit was realized from the operation.

Another foreign enterprise worthy of mention is at Chiksan, in the province of Chung-Chung. Here a gold-bearing formation may be traced for a distance of several miles along its strike, and development is now being carried on with joint American and Japanese capital, under the effective management of Messrs. A. W. Taylor and E. W. Mills, both American gentlemen, with long experience in Oriental mining and metallurgical work.

The native methods of mining are of the crudest form, and but a small proportion of the values is recovered. The Koreans do not use powder for mining. The ordinary method of procedure in the case of auriferous quartz is to build fires against the face of the ore-body, then throw cold water on the heated rock, and break off as much of it as possible with hammer and gad. The ore is then ground to powder between two flat stones, something after the manner of "bucking down" assay-samples, and this powder is panned for its free gold. Of course, none of the gold associated with sulphurets is thus recovered; and, since about one-half the gold in many Korean ores occurs in this condition, the wastefulness of the process is apparent. The development operations of the natives are frequently very laborious. At one place I saw a tunnel about 300 ft. long driven through granite to cut a copper vein in depth. The only tools used were the hammer and gad, and no fires were employed to heat and disintegrate the rock. The tunnel was of standard cross-section and very neatly trimmed to a smooth surface. Unfortunately, the copper vein, at the level where this tunnel cut it, proved too low in grade to be workable; so the project was a dead loss to the Korean gentlemen who financed it.

Placer-gold is found in almost every prefecture in Korea; but practically all the deposits are of too low grade to attract foreign capital, and the richer ones have long since been worked out. Gold-dust was demanded by China as her tribute from Korea during the long centuries of the latter's vassalage to the Sons of Heaven.

In the native method of placer-mining, a small stream of water is conducted through a ditch about 1.5 ft. wide and 8 ft. deep,

which is lined with stones. The auriferous gravel is excavated with small picks (the boulders being removed by hand), and shoveled into the ditch. The gold is recovered by panning the concentrates removed from the stone sluice, in large wooden pans. No mercury is used for amalgamating the gold. The native panners seem very careless; and a large part of the very fine gold is lost. Figs. 6 and 7 illustrate the general method of placer-mining in Korea.

Native metallurgical operations have gone into decadence in modern times, but there are abundant evidences that the ancient Koreans were very skillful in the art. For example, there hangs to-day near the town of Kyong-ju, on its great beam, a bell as large as the great bell of Moscow, which still gives forth its summons as deep and clear as the day on which it was cast, 1,400 years ago. Native mining operations are to-day confined to gold placer-mining in the manner described, copper-mining and smelting at the mine referred to, work upon a few small auriferous quartz-deposits, and iron-smelting on a small scale in several places. So far as I am aware, there are no producing silver-mines, though I have examined several which have been worked by the natives in the past. It may be noted in passing that nearly all the gold-quartz-veins in Korea occur in a granite country-rock—an association which is somewhat unusual, though not unknown, elsewhere.

Any considerable extension of either native or foreign mining enterprise in the future is not likely. The whole country, except in the extreme north, has been thoroughly examined by native and foreign prospectors, and most of the mineral deposite have proved to be too low in grade to invite development.

In company with an Australian mining engineer, I made a four months' trip through the northern central part of the country in the summer of 1906; and although several gold-, silver- and copper-prospects were examined, not one of them was sufficiently rich to warrant us in recommending it for purchase and development. The organization of our party may be of interest. We traveled with a pack-train of about 12 ponies, each led by his owner, called a "mafoo." The owner of the pony was paid according to the distance traveled, at a rate which varied from 3 to 9 cents per mile, according to local conditions in the different parts of the country. Out of this



FIG. 1.—TARACOL CAMP, ORIENTAL CONSOLIDATED MINING CO., UNSAN DISTRICT, KOREA.



FIG. 2.—CHEMULPO HARBOR, KOREA.

[ 9 ]



FIG. 3.—AMERICAN ELECTRIC CAR IN SEOUL.

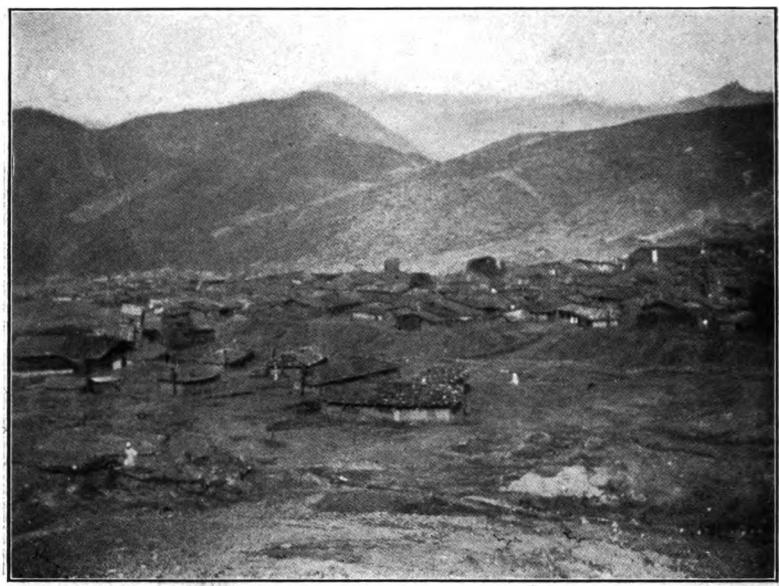


FIG. 4.—KOJIMDONG MINING-CAMP.

[ 10 ]



FIG. 5.—NATIVE FURNACES, KOJIMDONG.



FIG. 6.—PLACER-MINING OPERATIONS IN KOREA.

[ 11 ]



FIG. 7.—PLACER-MINING OPERATIONS IN KOREA.



FIG. 8.—A GROUP OF MAFOOS.  
[ 12 ]

amount the *mafoo* was obliged to feed and house himself and steed, and support himself on the return journey to his home. A photograph of the *mafoos* attending the party is represented in Fig. 8. An average day's journey was from 25 to 30 miles. There are few roads in the country; and practically all our traveling was done over rough mountain-trails. We had an interpreter, to whom we paid \$10 per month and his traveling expenses; an excellent cook, who received \$7.50 per month and expenses; and a "boy," who received the same. All of them spoke more or less English, and each was more or less proficient in the duties of the others. We two white men and our three servants rode on ponies lightly laden with bedding, etc., which, when skillfully disposed on the pack-saddle, made a very comfortable seat. The other ponies were laden with canned provisions and other necessary supplies. Some fresh provender could be purchased along the route—*e.g.*, eggs at 5 or 6 cents per dozen, and chickens at from 10 to 12 cents each. Upon arriving at a village where we intended to stop for the night, the interpreter or the cook selected the house which looked most inviting, and calmly installed our baggage in it without deigning to consult the wishes of the proprietor. If the latter offered objections (which was rarely the case), he was summarily ejected; and on our departure the next morning received about 10 cents to assuage his wounded feelings. If, on the other hand, he showed himself courteous and obliging, he was given a tip of 25 cents or half a dollar. We carried folding canvas cot-beds, with mosquito-net covers, as well as all cooking utensils, a wooden bath-tub, camp-stools, etc. Each white man had one pack-box about 1 ft. wide, 15 in. high, and 2.5 ft. long, in which to carry his belongings. All our pack-boxes were of this size, which proved a very convenient one. Bed-bugs were frequently encountered; and the first question asked of a prospective host was "Pintai isso?" which means "Bed-bugs have got?" The answer was too often "Yes;" and we became so familiar with them that we quite missed their friendly society when we returned to the effete civilization of Seoul. In several districts we were the only white men the natives had ever seen, and our woollen clothes, food, and manner of eating were objects of the liveliest curiosity. The Koreans are the most inoffensive and

good-natured people in the world, and one may travel anywhere in the interior with perfect security.

As laborers they are much inferior to the Chinese, except in underground mining, for which they seem to have a natural aptitude. The average Shantung coolie I consider the most efficient laborer in the world, if under proper supervision. He is strong, energetic, good-natured, naturally full of fun, and usually very tractable. The best feature of the labor-situation in Korea is the fact that Chinese and Koreans will never pull together, and a strike by one nationality may always be broken by employing the other.

To sum up the present industrial condition of Korea, it offers, on the whole (or at least it did offer, before the Japanese seizure of the country), an attractive field for carefully managed foreign enterprise. The labor question, as has been explained, is simple; the climate is very healthful, and does not differ greatly from that of New York; water is abundant, and power may be developed from it almost anywhere at small expense. Transportation is by bullock cart or pack-ponies. Fuel and timber are scarce; and this is the most serious drawback (aside from the political situation) to the successful prosecution of mining enterprises, and presents a question into which examining engineers should look most carefully. Where timber is found, it is usually oak or pine. As remarked above, the only extensive forest-areas are in the extreme north of the country, near the Manchurian frontier.

A paper dealing with Korea would be incomplete without some reference to the present unfortunate political situation. Under this head, however, I must be content to refer the reader to such recent and impartial books as: *Tomorrow in the East*, by Douglas Story; *The Passing of Korea*, by H. B. Hulbert; *The Truce in the East*, by B. L. Putnam Weale; and *The New Far East*, by Thomas F. Millard. Time will show whether, as these writers apprehend, Japanese influence will handicap the enterprise of other nations, or will really furnish for it the promised "open door."

## The South African Tin-Deposits.

BY WILLIAM R. BUMBOLD, BOLIVIA, SOUTH AMERICA.

(New York Meeting, April, 1907.)

WHEN I was in South Africa during the latter part of 1904, there were three known tin-fields, which may be called the Cape Town, the Bushveld and the Swaziland fields.

### THE CAPE TOWN TIN-FIELD.

This district is situated near Kuils river, 20 miles west of Cape Town, and 5 miles from Kuils River station on the Cape Town & Stellenbosch Railway. The deposits are in granite, intrusive in the Malmesbury beds, which are supposed to be of Silurian or Cambrian age. The granite, resisting denudation better than the surrounding shales, has formed low-lying hills, the highest of which, the Bottelary Berg, is 1,510 ft. above sea-level. The rock consists of quartz, orthoclase feldspar and biotite mica; tourmaline is also present. The feldspar occurs in large crystals. The rock is generally decomposed on the surface, and the decomposition sometimes extends as deep as 100 ft. This formation—granite intrusive in Silurian shales—extends for many miles to the northeast, but so far as I know the Kuils River deposits are the only ones now known to occur in it, though probably further prospecting will reveal other deposits. This particular discovery was accidental; alluvial tin being found in the course of boring for oil.

#### *The Kuils River Deposit.*

This comprises both lode and alluvial tin. The lode strikes N. and S., and dips about  $30^{\circ}$  E. into the hill. It is 5 ft. wide, and composed of dense white quartz, in which pinkish-gray cassiterite is distributed in large crystals. The vein also contains considerable quantities of wolfram.

Fig. 1 is a rough plan of the relative positions of the lode and the alluvial deposit, the latter, as shown, following the course of a stream, while the lode crops out on the hillside

above. The bed averages 2 ft. in thickness, rests on a bedrock of decomposed granite, and contains boulders of white quartz up to 2 ft. in diameter, and stones of the same material. It carries also between 15 and 20 lb. of cassiterite to the cubic yard. The cassiterite in the alluvium has the same pinkish-gray color as that in the lode above, from which it was obviously derived.

The origin of the lode itself is not so obvious. At first sight,

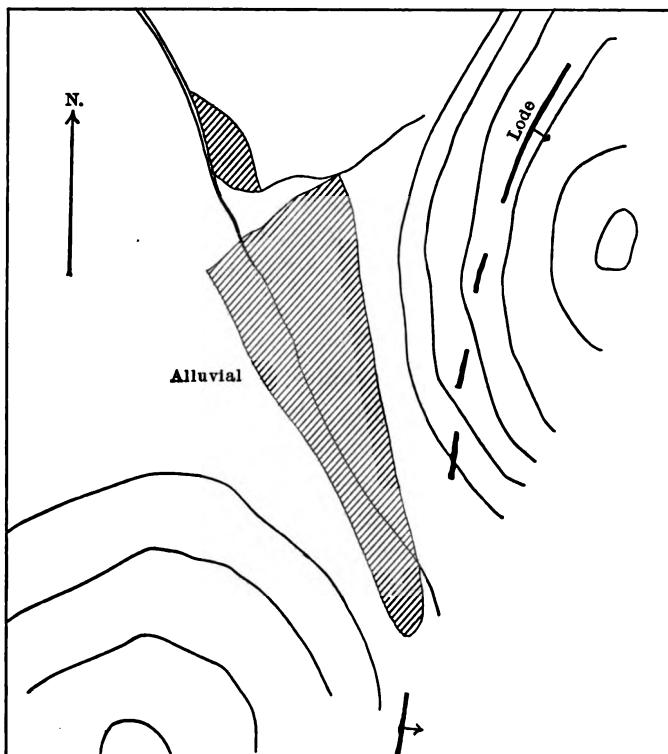


FIG. 1.—PLAN SHOWING THE KUILS RIVER TIN-DEPOSIT.

the large isolated cassiterite crystals reminded me of a pegmatite vein; but feldspar was not visible to the naked eye. There was a certain amount of chlorite, but no muscovite, nor did the vein in any way resemble a greisenized crack in the granite.

It might be either a fissure in the granite, in which meteoric waters had deposited quartz and mineral, or it might be an instance of magmatic segregation accompanied by pneumatolytic action. I incline to the latter hypothesis.

### THE BUSHVELD TIN-FIELD.

This district is situated on a farm called Enkeldoorn, 35 miles NE. from Hatherley, on the line between Pretoria and Delagoa bay. The country is granite; I did not examine its boundaries, but it is probably extensive. It is composed of quartz and feldspar, with very little mica. The feldspar is orthoclase, usually pink, and sometimes occurring in large well-formed crystals. The grain of the rock varies. Occasionally (and generally in the vicinity of the lodes) it is fine-grained, and approaches an aplite.

The ore-body, as I saw it, had a N-S. strike, dipped 80° W., was 1 ft. wide on the surface, and opened to 4 ft. in width a little below. It had no well-defined walls. The gangue was quartz, decomposed granite, oxide of iron and a little chlorite; and the amount of cassiterite did not appear to be large.

The deposit had only recently been discovered, and very little work had been done; in fact, none of the trenches had passed through the weathered zone, and no unaltered rock was to be seen. Owing to the shortness of my visit, and the small amount of work done, I hardly dare pass an opinion as to the origin of the deposit, but, on general principles, it should prove no exception to other occurrences of tin-ore in granite.

There was considerable excitement in Johannesburg over the new discovery at that time; and, according to newspaper reports, there have been other discoveries and a "boom" in tin-shares since. As to these new discoveries, I know nothing; but, if they resemble the one I visited, I fear they have been rated more highly than they will be when examined coolly and carefully by engineers accustomed to tin-deposits.

### THE SWAZILAND TIN-FIELD.

This district, situated on the border of the Transvaal and Swaziland, extends from Oshoek to Steynsdorp, and southeast to Embabane. The chief geological features are a hornblende granite, and a belt of highly metamorphosed, contorted schists, which divide the granite into two sections, the granite being intrusive in the schists. Fig. 2 is an ideal section from Oshoek to Embabane.

The granite mass varies in texture in different parts of the district, but at Oshoek it is fine-grained. Both the granite and

the schists are traversed by numerous dikes called diabase, but seen under the microscope, they prove to be diorite; moreover—a much more important matter for the tin-miner—the rocks are seamed by pegmatite veins, which are often so close together as to form a stockwork. These pegmatites are the source of the tin.

*The Oshoek Deposits.*

These deposits consist of stanniferous pegmatites and the alluvial beds formed from them. The granite is of the type mentioned above, but frequently it is foliated, and develops a banded structure, so as to be almost a gneiss. The pegmatite veins exhibit a coarse, crystalline intergrowth of quartz and feldspar, carrying a little hornblende, and sometimes a few large crystals of muscovite. Garnet, monazite, euxenite and

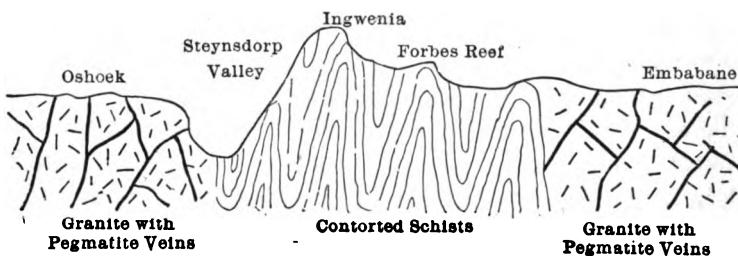


FIG. 2.—IDEAL SECTION OF THE SWAZILAND TIN-FIELD.

æschynite are found with the cassiterite, which occurs usually in large isolated crystals. The veins are in belts separated by tracts of barren granite.

Fig. 3, a sketch of the sections shown in the side of a cut at the mouth of a tunnel near Oshoek, shows the pegmatite veins in the hornblende granite.

Fig. 4, a sketch from the wall of a tunnel near Oshoek, shows, in addition, a dike of diorite.

The proportion of cassiterite in the pegmatite veins is small: 0.25 per cent. of "black" tin was the yield of the best sample I saw; and that was taken from the decomposed outcrop, where the tin had been, to a certain extent, concentrated. The veins, which may vary from 20 ft. to a few inches in width, are unfortunately too far apart to permit cheap extraction by quarrying.

The alluvium, which occurs in patches, along the streams in

the valleys, is not of great importance, although it has been the principal source of the tin thus far produced.

*The Forbes Reef Deposits.*

These deposits are situated 11 miles NE. of Oshoek, on the eastern side of the Ingwenia range. They occur in the belt of schists which divides the granite mass. These schists

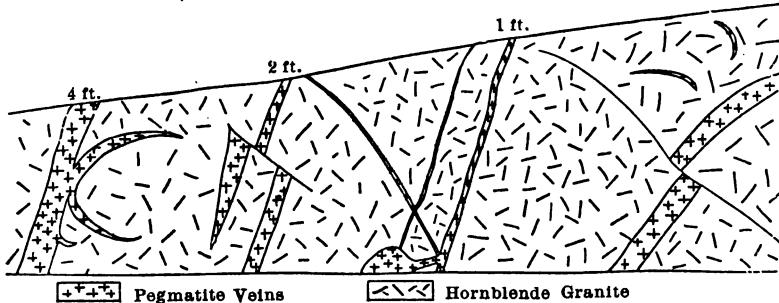


FIG. 3.—PEGMATITE VEINS IN HORNBLENDE GRANITE, NEAR OSHOEK.

vary greatly; but they consist chiefly of talc, hornblende and actinolite; and each variety is found repeating itself as one travels east or west, across their N-S. They carry, besides cassiterite, a great number of minerals, including gold, cinn-

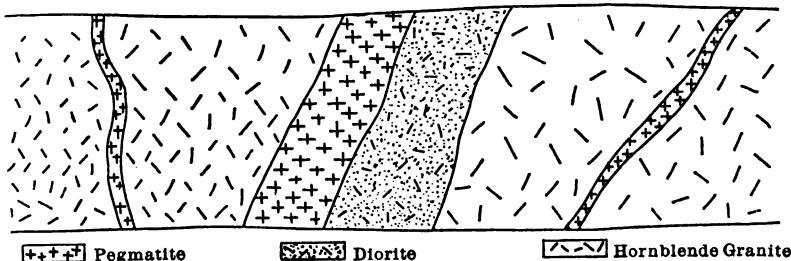


FIG. 4.—PEGMATITE VEINS AND DIORITE DIKE IN HORNBLENDE GRANITE, NEAR OSHOEK.

bar, scheelite, bismuth, monazite, euxenite, aeschynite, copper and iron pyrites, pyrrhotite, margarite, tourmaline, hornblende, talc, and actinolite. The tin occurs in veins in the schists themselves, and also in a fine-grained dike of aplite, in which the quartz and feldspar are intimately mixed, and which, having the same strikes as the schists, intersects them by virtue of its much flatter dip.

Fig. 5, a section near Forbes reef, shows both forms of occurrence. In the dike, the tin-ore is distributed throughout, in crystals and pockets; but not much could be learned about the deposit at the time of my visit, since only a few prospecting-trenches had been dug. The occurrence in the schists is most remarkable. The veins are not more than an inch wide, dip at a steeper angle than the aplite, and carry flat, tabular crystals of cassiterite imbedded in clay. The crystals have a fine amber color, and are laminated and brittle; sometimes, when scratched, they will break into powder like a Rupert's drop, showing the intense strain and pressure to which they have been subjected. Margarite is found in the schists in bunches, sometimes carrying a little tin.

The modern theory of pegmatite veins is that "while they may be to some extent the result of consolidation from a

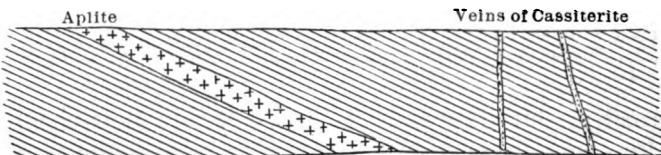


FIG. 5.—APLITE DIKE AND CASSITERITE VEINS IN BELT OF SCHISTS, NEAR FORBES REEF.

molten state, they are very largely of pneumatolytic origin" . . . . that they "are formed *after* the consolidation of the main mass of the igneous rock, and are to be considered as the last results of magmatic differentiation."<sup>1</sup> There seems no reason to depart from this theory for the origin of the pegmatite veins of the Swaziland tin-field, and one can only suppose the aplite dike and veins of Forbes reef to be likewise due to the pneumatolytic after-action of the granite below.

#### GENERAL CONCLUSIONS.

From an economic point of view, the South African tin-fields are, so far, distinctly disappointing. The Cape Town field offers the most encouraging prospect for future development. With regard to the sanguine views so early expressed concerning the

<sup>1</sup> "The Character and Genesis of Certain Contact-Deposits," by Waldemar Lindgren, *Trans.*, **xxxi.**, 242; reprinted by the Institute in *Genesis of Ore-Deposits*, 2d ed., p. 732 (1902).

Bushveld and Swaziland fields, one cannot help suspecting that some of the Johannesburg experts, though they may know all that is worth knowing about gold, do not possess a corresponding knowledge of tin-deposits and what constitutes payable and unpayable tin-ore. This is not necessarily to their discredit; an expert on one subject is not, for that reason, an expert on another.

I wish to repeat that the opinions here expressed are based upon the evidence as it existed a little less than two years ago, and not upon developments since made. On the other hand, many of the exaggerated valuations and over-confident prophecies to which I have referred must have been based upon nothing more than I had observed; for they were published at or very shortly after the time of my visit.

To take, for instance, the pegmatite veins: it was then doubtful whether the ore from these would average 0.25 per cent. of "black tin." When metallic tin is worth £130 a ton, the value of ore containing 0.25 per cent. of "black tin" is 4s. per ton—a pretty low value for ore that has to be mined and not quarried, where water-power is not unlimited, and when the place is 80 miles from a railway.

Nor does the character of the pegmatite veins warrant the confident expectation of richer ore in depth. I was informed, for instance, that the juncture of the pegmatite and the "diabase" would probably have the effect of enriching the deposit. But this "diabase" is distinctly later than the pegmatite, and is never, or very rarely, a tin-bearer; consequently, the idea that it will enrich a poor deposit is highly improbable.

Moreover, the method of sampling, which on the Rand has been reduced to an almost exact science, seems to be a matter of mere specimen-picking, when a tin-lode is the subject instead of a *banket reef*; whereas, the tin-lode should have double care bestowed on it, because its values are bound to be more erratic than those of the Rand formation.

I sincerely wish for the South African tin-fields all the success new mining enterprises deserve, but before they begin to figure in the world's tin-production, something better will have to be found than what I saw in 1904.



## Dip and Pitch.

BY R. W. RAYMOND, NEW YORK, N. Y.

### POSTSCRIPT.

SINCE the presentation of my note on this subject<sup>1</sup> at the New York Meeting, Prof. Louis has pointed out an error in my statement of his conception of "pitch"—namely, he understands the pitch, in the restricted sense which he proposes, to be the angle of inclination of the axis of an ore-body, measured on the vertical plane drawn through the body; whereas, I represented him as proposing to define "pitch" as the angle of inclination

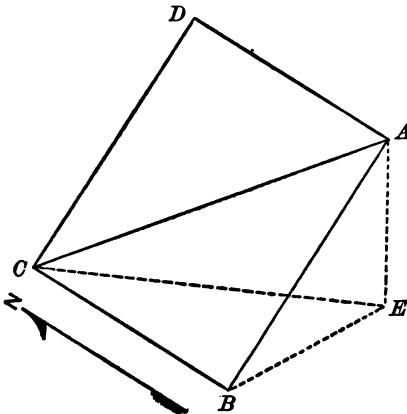


FIG. 1.—ISOMETRIC PROJECTION, SHOWING POSITION OF PLANE OF BED OR VEIN, AND AXIS OF ORE-BODY THEREIN.  $ABCD$ , plane of vein;  $AC$ , axis of body;  $AB$ , vertical;  $BC$ ,  $CE$  and  $BE$ , horizontal.

of an oblique body, measured on the plane of the dip, in the direction of the strike. The difference will appear upon consideration of the accompanying isometric projection, Fig. 1, in which  $ABCD$  represents the plane of the inclosing ore-deposit (vein or bed), and  $AC$  the axis of the oblique ore-shoot.  $ABE$  is the angle of the dip, as universally understood; and  $ACE$  is, according to Prof. Louis's proposal, the angle of the pitch, which is measured in the vertical plane  $ACE$ . But, in my re-statement of his proposal, I made  $ACB$ , measured in the plane  $ABCD$ , to be the pitch. Since his original communication con-

<sup>1</sup> *Bi-Monthly Bulletin*, No. 20, March, 1908, p. 195.

tained this diagram, there is no excuse for my misunderstanding of it. But there is an explanation, which seems to me more important than an excuse—namely, without carefully studying Prof. Louis's illustrative diagram, I hastily assumed that his conception of "pitch" was that which I had myself entertained for many years, and believed to be entertained by American mining engineers generally.

Was I wrong as to that usage? I hope the members of the Institute will help me to decide this question. In recalling the sources of my own impression, I realize that in American practice I have seldom or never heard of "pitch" as an angle distinct from the dip, and independently determined by survey. Our mine-surveyors recognize, but do not employ, the old usage of "dip" and "pitch" interchangeably; and I think they generally apply the term "pitch" to the case named by Prof. Louis at the beginning of his communication, as follows:

"It is well known that the ore-shoots in a mineral vein do not, as a rule, coincide with the dip of the vein, but make an angle with it; in the same way, lenticular masses often are oblique to the direction of maximum dip of the plane in which they lie. We have no word to designate this obliquity in either case."

According to my view of American practice, the direction of the pitch is usually stated in terms of the strike. Thus, if a vein strikes N. and S., an elongated oblique ore-body in it is usually said to pitch north or south in the vein, whatever be the dip. According to Prof. Louis's definition, the pitch would have a new strike of its own; and an ore-body could not pitch north or south in a N-S. vein unless the latter were vertical. Moreover, the American usage, as I understand it, furnishes exactly what Prof. Louis says is needed—namely, a measure of the "obliquity" of a lenticular mass "to the direction of the maximum dip of the plane" in which it lies. The line of maximum dip and the line of the axis of the oblique body both lie in the plane of the dip; hence, it seems to me, the angle between them is to be directly measured in that plane.

Moreover, this method of estimating pitch is the most convenient for the practical miner. The pitch of the ore-body determines how far he must run each successive level to reach it; and, since he runs these levels on the plane of the dip, his

guiding measurements should be made with reference to that plane.

Again, the inclination of an ore-body, on the plane of the dip, "to the direction of maximum dip" is a thing the miner wants to know, and to use daily. If we do not call it the pitch, then we must have another name for it. But the exact course and inclination which Prof. Louis wishes to call "pitch" is something that the miner does not thus need and use. The course and dip of the vein or bed having been determined, he naturally refers to that plane all other directions, dimensions, and angles involved in the work of mining. The whole mine appears to his thought like a picture drawn upon that plane. In fact, the mine-maps often include a profile, representing the workings on the plane of the vein, which is for many purposes more convenient than a projection of them upon a vertical plane. In presenting mining cases to judges and juries, I have often found the "profile" to be more easily understood than the vertical section and projection.

Perhaps my greatest objection to Prof. Louis's "pitch" is, that it introduces a new course, whereas mine retains only the course of the vein. In a private letter, Prof. Louis defends his definition (referring to the diagram given above) as follows :

"I call  $ACE$  the angle of pitch, because it has a real physical meaning; it is the actual angle of inclination of the line  $AC$  (the axis of the ore-shoot) to the horizontal, and no other angle is. If I want to sink a shaft to follow the axis of the ore-body, and, needless to say, that is what I do want, I must set out my shaft at the angle  $ACE$ , and of course in the azimuth of the line  $EC$ . Furthermore,  $ACE$  is easily measured in practice, whilst it would be rather difficult to measure the angle  $ACB$ ."

To this I reply that in my experience it has been very rare that inclined shafts have been sunk to follow the axes of inclined ore-bodies. The ordinary practice is to sink either vertical shafts, outside of the veins, or inclined shafts within it, following the dip. In either case, the levels are run on the strike, and the ore-bodies are cut by the levels. Prof. Louis overlooks the circumstance that several ore-bodies, pitching at different angles (and sometimes, though seldom) in different directions, often occur in the same mine. It is not usual to develop these by separate shafts, following their axes.

Nor do I see that it is easier in practice to measure  $ACE$  than  $ACB$ . In fact, however, the pitch  $ACB$  is usually first stated qualitatively, not quantitatively; and the mine-development afterwards measures it. The commonest way of stating it is not in degrees and minutes. For instance, the miner says his vein strikes north and south, and dips east, while his ore-body pitches north or south so many feet to the hundred. If he were told that the said ore-body really "pitched" N.  $39^{\circ} 42'$  E., he would not understand why this odd new element had been introduced into the problem which was so simple without it.

#### DISCUSSION.

PROF. HENRY LOUIS, Newcastle-on-Tyne, England (communication to the Secretary):—Dr. Raymond's interesting note and postscript furnish an admirable example—if such were indeed needed—to prove how far mining still is from being a science. The fundamental need of an exact science is precision in definitions; and here we see that Dr. Raymond and myself are proposing to define differently a word, in common use among miners, which each of us has used scores of times without suspecting that the other could understand thereby anything different from his own conception of it.

There is, of course, no difference of principle involved. It is merely a question of convenience, whether it is better to measure the angle of pitch in the plane of the vein or ore-body, or in the vertical plane in which it lies. I prefer the latter method for various reasons.

In the first place, it is more scientific, because when we speak of the angle of inclination of any straight line to the horizontal, we always mean the angle as measured in a vertical plane, and there seems to be no reason why we should make an exception in this particular case; furthermore, by following this general geometrical practice, there is no need to state more than this one angle; whereas, if we adopt Dr. Raymond's method we must state not only his angle of pitch, but the angle of dip of the plane in which it is measured, before we know what the real inclination to the horizontal is. I admit that in the majority of cases it makes no practical difference, because the plane of the vein is so nearly vertical, and the pitch also is generally rather steep; and further, as Dr. Raymond says, we usually speak of it in somewhat lax terms. I admit also, that,

as he says, "if a vein strikes N. and S., an elongated oblique ore-body in it is usually said to pitch north or south in the vein, whatever be the dip;" but in saying this, I understand that the ore-body pitches northwards or southwards, as the case may be, and not that its azimuth is due north or south; I cannot agree that my definition postulates a new strike for the pitch. The direction of strike, which is the azimuth of a horizontal line in the ore-body, is not affected at all; and my method affords an easy means of determining the azimuth of the ore-body, in the few cases where this is required to be determined, whilst this is less easy to calculate from Dr. Raymond's definition. It is, of course, quite usual, as Dr. Raymond says, for the pitch to be measured not in degrees, but by the number of feet of horizontal displacement to a given height; I should fear that Dr. Raymond's method would lead miners to speak of the height between two levels not in terms of true vertical height, but in terms of distance apart measured along the plane of the vein.

To be quite fair, I may perhaps be allowed to digress sufficiently to explain that for many years past I have never used projections on the plane of the vein, but always horizontal and vertical projections; *e.g.*, in measuring up ore-bodies, I always use for veins: horizontal thickness into vertical height into length along strike, and for beds: area in plan into vertical thickness, and I feel sure that the engineer who has given this system a trial will never revert to the old method of employing true thickness instead of horizontal or vertical thickness, as the case may be. This practice has caused me to avoid projections on the plane of the vein, and I find that it simplifies my surveying work immensely. I have already said that in the majority of cases, where mineral veins are concerned, it does not matter very greatly which definition of pitch we work to. But in the case of oblique lenticular masses, which we so often have to deal with in European mining practice, the plane in which these lie is often comparatively flat and their pitch is often considerable; in these cases, it is usual, and is perhaps the best practice, to develop the ore-bodies by means of an inclined shaft along or parallel to the axis, and in that event my angle of pitch is the angle of inclination at which the shaft has to be sunk, whilst Dr. Raymond's is not, although the former can, of course, be calculated from the latter, if the dip of the plane of the ore-body be also known.

In proof of the real practical importance of the knowledge of this angle of pitch, I may say that last summer, in the course of my regular professional work, I came across two instances, within three months, of mines where such lenticular ore-bodies had been lost, and had to be picked up by drifts, because the shafts had been laid out to follow the angle of dip instead of the angle of pitch, as defined by me.

I repeat, however, that I do not think that it matters very greatly which definition of pitch we adopt; the essential thing is that we shall definitely decide upon one, and keep to it.

**DR. RAYMOND:**—I am heartily grateful to my friend, Prof. Louis, for his candid and lucid criticism, which, however, serves rather to define and emphasize the difference between us, than to adduce new considerations, calling for rejoinder from me. In fact, I could not contradict Prof. Louis's statements, because they are true; and, as to one of the two questions involved in this discussion, they must be weighed, not thrown out.

The two questions to which I refer are these: (1) which of the two definitions of "pitch" is theoretically the better—that is, which would be preferable if the term were a new one, and we were entirely free to fix its meaning? and (2) which of them is now employed by the larger number of intelligent English and American mining engineers?

It is evident that if Prof. Louis's definition of "pitch" were accepted, what I call "pitch" would need a new name—and *vice versa*; and it is probable that the question which pitch should hereafter be the standard pitch would be largely affected by the extent of the present intelligent usage. It is much easier and wiser to introduce a new name for a new conception than to introduce a new meaning for an old and familiar name. I hope, therefore, that engineers in both countries will freely express their views and report their practice in this respect.

After 45 years of professional practice, I am convinced that it is much better to have such questions thoroughly discussed than arbitrarily and prematurely decided. If the discussion of this particular question should last a long time, all the better. Engineers can easily avoid all embarrassment to themselves or others by simply stating, when they speak of "pitch," in what plane the pitch they mean is measured.

## The Uniform Nomenclature of Iron and Steel.

A Discussion of the Paper presented at the New York Meeting, February, 1908, and printed in *Bi-Monthly Bulletin*, No. 20, March, 1908, pp. 227 to 237.

**HENRY D. HIBBARD**, New York, N. Y. (communication to the Secretary\*):—The definition of steel, given on p. 235, does not seem to fit perfectly the requirement that it shall include all known varieties of steel and exclude everything else. The first requirement, that it shall be malleable at some temperature, is also possessed by some varieties of gun-iron—that is, mottled cast-iron, of which cannons have been made in the past by the South Boston Iron Co. and others. Gun-iron also meets the requirement (A) in being cast into an initially-malleable mass. The malleability was indeed not great, nor was it made use of except to demonstrate the quality of the iron, but it approached in measurable degree that of some of the alloy-steels. As for requirement (B), some puddled-irons having from 0.2 to 0.8 per cent. of carbon may be hardened greatly, although this property is not utilized.

Of course, unusual properties in some of a class of irons which give them no value and do not add to their usefulness are of no practical importance or effect except as they interfere with the definition.

It has seemed to me that the usual meaning conveyed in using the word steel, rests on its unique valuable properties which are actually utilized, and that the following definition meets fairly well the case in covering the commercial steels and perhaps all steels as we actually know them.

“Steel is a variety of iron which, at some temperature, is malleable to a useful degree; it is made by a fusion-process, or when not so made is capable of being hardened to a useful degree.” By the term “useful” in this definition is meant such as is actually utilized in practice.

The theoretical objection to this definition is that there is no dividing-line between useful and non-useful degrees of malle-

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\* Received Mar. 3, 1908.

ability and hardening, but it is not at present difficult to say that a given piece of iron the properties of which are known is within or without the limits of the definition, and if doubtful cases arise in the future some way may then be found to define them.

WILLIAM KENT, Syracuse, N. Y. (communication to the Secretary\*):—I suggest that the terms “weld-iron,” “ingot-iron,” “weld-steel,” and “ingot-steel” be starred as obsolete or obsolescent. They were arbitrarily introduced by the International Committee at Philadelphia in 1876, and were adopted by a few writers of books and technical papers at that time, but they have never been introduced in commerce.

I think it is useless to make any distinction between the generic and the specific definitions of cast-iron. Cast-iron is iron containing so much carbon or its equivalent that it is not malleable at any temperature, whether it is in the shape of melted metal in the ladle, or is run into pigs, or is in the form of castings. The long paragraph attempting to explain the difference between the generic and the specific use of the term “cast-iron” might be applied to any other material whatever, such as stone, brick or wood. Thus, generically, stone is a hard material found in the earth’s crust; and specifically, stone might be defined as the same material made into the form of sculptured blocks. The term “cast-iron” is used in common language to mean a metal which is distinguished from steel and from wrought-iron, and whether it is a specific or a generic term makes no difference.

I regret to see that the Committee recommends that a line be drawn between cast-iron and steel at 2.20 per cent. of carbon. The present Committee should have profited by the experience of the former International Committee (Philadelphia, 1876), and realized that no committee can change the meaning of words commonly used in the English language. That Committee failed in its attempt to get people to distinguish between “ingot-iron” and “ingot-steels,” and the present Committee will fail to establish 2.20 per cent. of carbon as the dividing-line between cast-iron and steel.

Professor Wedding’s dissent from drawing any line between cast-iron and steel is exactly right, if he means that a line

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\* Received Apr. 7, 1908.

should not be drawn by a committee. The definition of terms will be settled by commerce and by common usage and not by a committee. In the United States, as in Germany, every metallic product of the blast-furnace is called "pig-iron" or "cast-iron," except possibly when the product has a specific name, such as "spiegeleisen."

With regard to the statement that cast-steel is the same as "crucible-steel," the term "cast-steel" is gradually being expanded by commerce to have the same significance as the adjective "steel-cast." A cast-steel crank would be a crank cast out of either crucible, open-hearth, or Bessemer steel, distinguishing it from a forged steel crank, and the adjective "steel-cast" would not be applied to it by one person out of a hundred thousand. The statement that the term "cast-steel" should be avoided because "confusing and because a temptation to fraud" had better be left out. Manufacturers of steel sell their product for what it actually is under its proper name, "crucible," "open-hearth," or "Bessemer," and as to products made out of forged steel, such as cutlery and springs, there is no reason for there being a temptation to fraud, because the hardware trade does not distinguish between these grades of steel in selling these products.

"Plate-iron. The name applied in Great Britain to refined cast-iron." I think the name is not quite obsolete in this country, for cast-iron is still for some purposes refined in the run-out fire and run into plates which are called "plate-iron."

"Refined iron" and "double refined iron" are terms which might be inserted in the definitions, meaning wrought or puddled iron which has been refined by one or more re-rollings.

The question of establishing a boundary between steel and iron was thoroughly discussed by the Committee of 1876, which decided that the line should be between hardening and not-hardening. This decision was never accepted in commerce, and it is just as useless now to try to draw a line at 0.82 or 0.20 per cent., or any other percentage of carbon. Mr. Pourcel is entirely right in saying that steel should include all forms of iron freed from slag by fusion and cast in a malleable condition. This is exactly the definition for which Holley contended more than 30 years ago. It is the definition that has been consistently adhered to in the trade ever since Bessemer steel was

first made, and it has been incorporated in the United States tariff laws. No matter what any committees may determine as the boundary-line between steel and iron, commerce and the usage of the people will determine finally the definition.

I inclose a classification of iron and steel which is substantially the same as the one I contributed to the *Railroad and Engineering Journal* in April, 1887.<sup>1</sup> I think it is still a good classification and I have not been able to improve it.

*Classification of Iron and Steel.*

| Generic Term.           |  | Iron.                                   |  |   |   |
|-------------------------|--|---|--|---|---|
| How Obtained.           |  | Cast,<br>Or obtained from a fluid mass. |  | Wrought,<br>Or welded from a pasty mass.  |   |
| Distinguishing Quality. |  | Non-malleable.                          | Malleable.   | Will Not Harden.  | Will Harden.  |
| Species.                |  | Cast-Iron.                              |  | Cast-Steel.   | (7) Wrought-Iron.<br>(8) Wrought-Steel. <sup>†</sup>  |
| Varieties.              |  | (1) Ordinary castings.                  | (2) Malleable cast-iron, obtained from No. 1 by annealing in oxides. | (3) Crucible,<br>(4) Bessemer,<br>and<br>(5) Open-hearth steels.<br>(6) Mitis.* | a. Obtained by direct process from ores, as Catalan, Chenant, and other process irons.<br>b. Obtained by indirect process from cast-iron, as finery-hearth and puddled irons.<br>Obtained by direct or indirect process, as German, shear, blister, and puddled steels. |

\* No. 6. Mitis is the name given to a new product (having the same general properties and produced by the same processes as soft cast-steels) made by adding an alloy of aluminum to melted wrought-iron or soft steel before pouring.

† No. 8. Wrought-steel is almost an obsolete product, having been replaced in commerce by cast-steel.

Sub-varieties of Nos. 3, 4, and 5, soft, mild, medium, and hard steels, according to percentage of carbon, the divisions between them not being well defined.

Cast-iron usually contains over 3 per cent. of carbon; cast-steel anywhere from 0.06 per cent. to 1.50 per cent., according to the purpose for which it is used; wrought-iron from 0.02 per cent. to 0.10 per cent. The quality of hardening and tempering which formerly distinguished steel from wrought-iron is now no longer the dividing-line between them, since soft steels are now produced which, by the ordinary blacksmith's tests, will not harden. All products of the crucible, Bessemer, and open-hearth processes are now commercially known as steel.

HENRY M. HOWE, New York, N. Y. (communication to the Secretary\*):—Mr. Hibbard objects to our distinguishing steel from cast-iron by holding that steel should be malleable at some temperature, while cast-iron is not. I have proposed that we should modify this definition by saying that steel must be use-

<sup>1</sup> Vol. lxi., No. 4, p. 158 (April, 1887).

\* Received May 8, 1908.

fully malleable, which I think meets his objection. I am not sure that it is necessary to insert the word "usefully," because the definition would appear on its face to imply a useful degree of malleableness. Almost all metals, and, indeed, almost all solids, are somewhat malleable. Even gray cast-iron is slightly malleable. I think that a definition based on malleableness would be understood by all reasonable persons as implying useful malleableness. But I see no objection to introducing the word useful.

The trouble with Mr. Hibbard's definition, which certainly is extremely brief and clear, is that it is not accurate unless we introduce a special definition of a fusion-process to make it exclude processes like puddling. Surely puddling on its face is a fusion-process. I fear that his introducing "fusion-process" would be a process of confusion.

Professor Kent's criticisms seem in general to be based on misinformation.

He is mistaken in supposing that the term "ingot-iron" has not been introduced in commerce. It is still used in commerce and may play an important part.

He is mistaken in supposing that it is useless to make a definition between the generic and specific meanings of cast-iron. This error of his is evidently based on his overlooking the fact that a large body of men, including some distinguished writers, maintain that pig-iron is not cast-iron, and that "cast-iron" can be used only to designate pig-iron which has been remelted and cast into castings. In short, there is an important group of men which recognizes at present only the specific meaning. On the other hand, there is a very large group which recognizes the generic meaning. Both meanings are in existence, as the committee knows, and its clear duty is to co-ordinate these two meanings.

Professor Kent is in error in supposing that the committee does not realize "that no committee can change the meaning of words commonly used in the English language." Our committee distinctly recognizes that, and has made no attempt to change the meaning of any word. Professor Kent, of course, understands that to propose a line where none previously existed is not to change the meaning of words. If the committee had attempted to change a line previously existing then

it would have deserved Professor Kent's censure, but it has attempted nothing of the kind.

Professor Kent knows that "the present committee will fail to establish 2.20 per cent. of carbon as the dividing-line between cast-iron and steel." How does he know that?

Professor Kent is mistaken in supposing that, if the usage of the public must dispose, a committee cannot profitably propose.

Professor Kent is mistaken in supposing that wrought-steel is an almost obsolete product. An enormous quantity of blister-steel is bought and sold currently, and this will probably continue to be the case. This is certainly wrought-steel.

### The Bogoslovsk Mining Estate.

A Discussion of the Paper of William H. Shockley, presented at the New York Meeting, February, 1908, and published in *Bi-Monthly Bulletin*, No. 20, March, 1908, pp. 197-226.

H. W. MUSSEN, Collingwood, Ontario, Can. (communication to the Secretary\*):—Doubtless all engineers who have paid more than a casual visit to Russia have come into contact with that formidable document, the "*snieta*," or estimate of the Russian manager. It is an institution which seems to be inseparable from Russian mining methods. As Mr. Shockley points out, the year's costs "agree very closely" with the figures of the *snieta* made at the beginning of the year. In cases which have come under my notice, I have been satisfied that there had been a good deal of "rigging" of accounts to this end. The sum spent by the manager was carefully kept down to the total of the estimate, because it was well known that no more money would be forthcoming, and when this is done it is not a difficult matter to see that the right amounts come under the right heads in the final accounts. I do not say that this is always the case, but I have come across notable instances. Looking at it from the Russian owner's point of view, I think that the balance of the argument is usually in favor of the *snieta* as limiting "impulsive indiscretion" on the part of managers.

The Russian Mining Code of to-day leaves much to be desired, but this is thoroughly appreciated by the official world there, and great changes are spoken of for the future. In many, if not in most, cases the laws are interpreted liberally, and a great deal is left to the discretion of the district mining engineer or inspector, with whom it is necessary to keep in close touch.

As Mr. Shockley points out, the officials of a mine, who are always Russians, are held personally responsible for accidents resulting to employees, quite independently of any compensa-

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\* Received Apr. 2, 1908.

tion which may be made to the sufferer. This seems startling enough, but I have always found that a penalty is imposed only where gross negligence on the part of the company's officials is proven in court. A great many cases go to trial, but very few result in punishment.

The great number of holidays kept by Russian workmen is, indeed, a trial to one who is trying to push on work during a short summer season. Each mine or company working has prepared for it an official list of days upon which work may not be demanded of the men; but this does not apply to certain forms of employment, such as blast-furnace work, pumping, etc., which, from their nature, must be carried on continuously. In such cases it is provided that, if the shift is more than 8 hr. long, 4 days in each month must be given as rest-days. If the shift is 8 hr. or less full time may be demanded each month. It is usual in Russia to pay 50 per cent. additional wage for working on legal holidays, and this goes a great way towards keeping the work going steadily.

Mr. Shockley's paper is intensely interesting and valuable to any one operating in Russia, as the Bogoslovsk Estate is one of the most important mining enterprises of the Empire.

### The Vein-System of the Standard Mine, Bodie, Cal.

Discussion of the paper of Mr. R. Gilman Brown, *Trans.*, xxxviii., 343.

H. W. TURNER, Portland, Ore. (communication to the Secretary\*):—Mr. Brown's paper on the complicated groups of veins exposed in the workings of the Bodie mine forms a valuable contribution to the literature of the structural features of ore-deposits. It is much to be desired that managers should put into print the results of their observations of the mines under their charge. These observations, as well as data of production, kind of ores, etc., usually accumulate for years, and unless the mining geologists of the Geological Survey happen along before the mine is worked out, such data seldom get into print.

About the year 1899 I went through the mines at Bodie with Mr. R. C. Turner, then superintendent, and made some notes on the veins and gangue-minerals, and collected some specimens.

Mr. Brown refers to crystals of feldspar (albite) found on fragments of quartz on the surface. I collected a number of specimens of these crystals, mostly from Queen Bee hill, and had thin sections made of them for microscopic study. To my surprise, the examination of these thin sections showed that in all the sections the original mineral had been replaced by quartz. In other words, these crystals were pseudomorphs. As a study of the crystal forms with a goniometer was not made, I did not ascertain their original nature, but presumed them to have been feldspars. It will be noted that Mr. Brown likewise calls attention to the fact that some of these crystals were mere shells.

In a paper on Bendigo Veins,<sup>1</sup> Mr. Waldemar Lindgren describes the occurrence of albite in drusy cavities intergrown with quartz. He also calls attention to the occurrence of albite and a form of orthoclase in veins at other places.

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\* Received Mar. 23, 1908.

<sup>1</sup> *Economic Geology*, vol. i., No. 2, p. 163 (Nov.-Dec., 1905).

Among the specimens of vein-matter collected at Bodie were some of banded chalcedonic quartz, showing thin seams of a clayey nature. It is quite possible that these clay-seams represent original feldspathic layers.

Under the head of dikes, Mr. Brown refers to the "Red Ledge" that cuts the Fortuna vein. I took a sample of this soft, sugary, dike-rock, and a portion of it was analyzed by Dr. W. F. Hillebrand, of the U. S. Geological Survey, who obtained the following results:— $\text{SiO}_2$ , 74.74;  $\text{CaO}$ , 0.14;  $\text{Na}_2\text{O}$ , 0.21; and  $\text{K}_2\text{O}$ , 10.57 per cent.

Evidently this dike is of the nature of an aplite or a rhyolite. My notes describe it as thoroughly granular, and if this is correct, the dike is an aplite. So far as I know, aplite dikes in the Sierra Nevada have never been found intruded into Tertiary volcanic rocks. They are most common in granitic areas, but sometimes occur in the slates surrounding the granitic masses, as on the east slope of Mt. Conness, a few miles to the south of Bodie. It would therefore be interesting to have the nature of the "Red Ledge" dike determined with certainty.

The aplites of the granitic areas are regarded as allied to pegmatites, into which they grade, and to have filled contraction-cracks and fissures in the cooling granitic magma.

Since the basic elements in a given magma usually crystallize out first, the residuum is relatively richer in silica and the alkalis. This aqueo-igneous residual magma, filling cracks and fissures, forms aplite and pegmatite dikes.

In the old lower workings of the Bodie mines, there is often on the timbers and elsewhere an efflorescence of white silky fibers. This is magnesium sulphate, so common in old quicksilver-mines.

### **Chlorination of Gold-Ores ; Laboratory-Tests.**

Discussion of the paper of A. L. Sweetser, *Trans.*, xxxviii., 236.

**CHARLES H. WHITE**, Harvard University, Cambridge, Mass. (communication to the Secretary\*) :—Those interested in leaching-processes gladly welcome contributions on either laboratory-tests, such as are reported by Mr. Sweetser, or mill-tests made on larger quantities of ore; and especially valuable are such reports, even with negative results, if the methods adopted are the outgrowth of an intimate knowledge of the conditions to be met. It seems very desirable, therefore, that as complete details as possible be given in reporting on such tests, particularly with respect to the character of the ore under examination. The questions of prime importance in the sampling of ore and in the making up of charges for laboratory-tests are those respecting its grade and uniformity. In Mr. Sweetser's paper the first of these questions is answered definitely, but the answer to the second, although apparent on inspection of the results, might be more strongly emphasized with advantage, since it is only on account of the extreme uniformity of the ore that the satisfactory results obtained could have been expected. It seems advisable to call attention to the fact that for average ores, and more particularly for uneven, or "spotted" ores, the quantities used by Mr. Sweetser are not usually regarded as sufficient to insure satisfactory results.

Let us examine the method somewhat in detail. The ore was crushed to pass a 5-mesh screen, and a sample of 45 lb. was taken out for assay and tests. The diameter of the largest grain of this ore, according to Richards,<sup>1</sup> was 2.67 mm.—assuming here, as in the following cases, that the wire of the screen was of the largest size used for the purpose, thereby giving any possible advantage in this respect in favor of the method. The table in Richards's book, p. 852, shows that 45 lb. is a sufficient quantity for a fair sample with uniform ores, but not sufficient

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\* Received Nov. 27, 1907.

<sup>1</sup> *Ore-Dressing*, vol. ii., p. 1196 (1903).

if the ore is uneven or of high grade. The 45-lb. lot was then rifled down without further crushing to a sample for assay of not more than 5 lb., which would be sufficient only in case of "very low grade or very uniform ore." The remaining 40 lb. was divided into four 10-lb. lots, which were crushed to pass 10-, 12-, 20-, and 30-mesh sieves respectively. According to Richards, the maximum grain in each case is respectively 1.35, 1.07, 0.69, and 0.44 mm., and his Table 369 shows that, with the most favorable ore, it is only the 30-mesh material that is sufficiently fine for so small a sample as 100 g.—the amount used for the tests—to be a representative portion. Notwithstanding this, Mr. Sweetser reports in Table III. the assays of four different lots of tailings which agree exactly with the assay of the original ore. The conclusion is therefore drawn that his ore was of rare uniformity, and this fact, no doubt, accounts in a large measure for his satisfactory results.

In dealing with such small quantities it seems unsafe to calculate the percentage-extraction from the assay of the tailings alone unless the ore is absolutely uniform. It is obvious that, with average ores, correct results by such a method could hardly be expected. It might easily happen that the tailings would assay higher than the original ore, and yet there might be a fair extraction. It seems to me much safer to assay the solution also, and thus have a check; the assay to be made, not by precipitating the gold as sulphide and filtering, as is suggested, but in the manner usually practiced of evaporating in a dish with litharge and assaying the residue, or evaporating in a glass beaker or dish of lead-foil, and running the residue through the furnace with its container. In dealing with tailings alone, it should be borne in mind also that there is a possible addition to the tailings of calcium sulphate from the charge, and also a possible shrinkage of tailings through the solution of other constituents than gold.

I think Mr. Sweetser is hardly justified in his statement that the fines were "obviously thoroughly leached," for in Table III. it is shown that the highest extraction was from the coarsest material, and that from the finest material nothing was extracted.

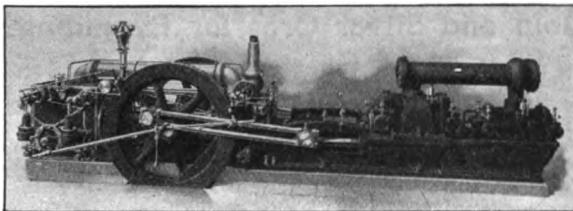
The peculiar result in Table II., that the finer the crushing the poorer the roast, may be explained on the assumption that

the finer ore bedded and was not stirred. Another interesting result set forth in Table IV. is that the longest treatment—5 hr.—gave the poorest results, and that the 4-hr. tests were worse than those of 1 hr. In these tests the fact that the ore was not thoroughly roasted might account for the precipitation of part of the gold after solution, if the quantity of chlorine present were not sufficient. Unfortunately, we are not able to estimate the chlorine pressure, since the capacity of the bottle is not given nor the quantity of water used in the charge, even if we could assume that the bleaching-powder was fresh and up to the usual standard in chlorine-content.

In the statement of the analysis of the ore, one of the constituents given is ferrous sulphide (FeS); also, there is an undetermined 3 per cent. in the report of the analysis, which is not mentioned. This is probably a typographical error. This statement refers only to ferrous sulphide (FeS).



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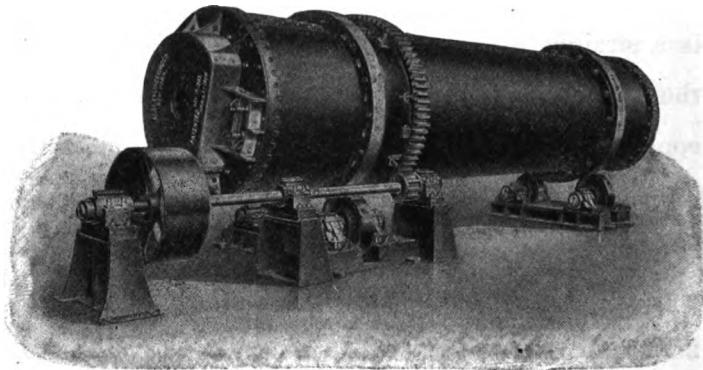
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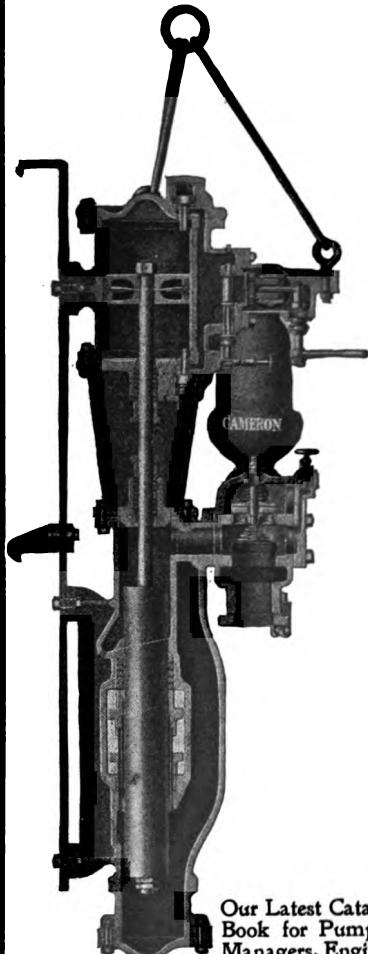
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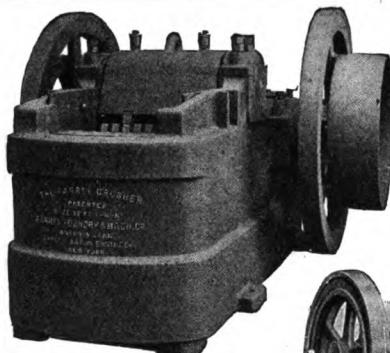
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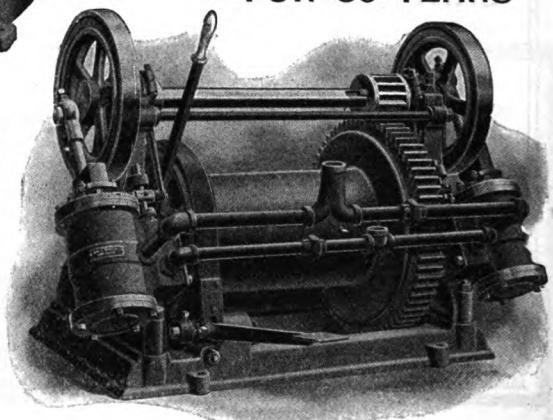
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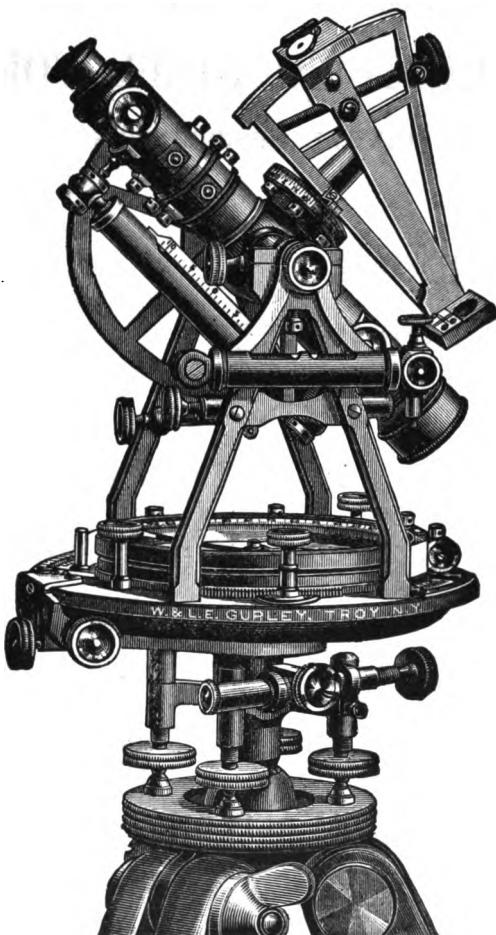
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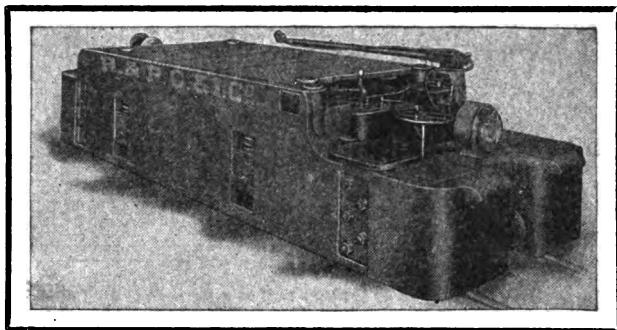
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